A Comparison of Harvesting Systems for Western Juniper

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Abstract

Western juniper (*Juniperus occidentalis*) is considered a relatively untapped source of woody biomass with potential to serve as a significant feedstock for regional wood-to-energy systems. A barrier to further development of this market is a lack of information concerning the productivity and costs of juniper harvesting systems. One published study and three unpublished case studies of harvesting western juniper are compared using consistent stand and site variable values and machine costs. Felling, skidding, and log processing processes are compared across a range of conditions. Stump to landing harvesting costs for average conditions ranged from approximately \$35/tonne(\$32/ton) to \$96/tonne(\$87/ton), averaging \$74/tonne(\$67/ton). A lack of robust estimators of juniper volume is identified as a critical research need to aid in the development of western juniper as a woody biomass feedstock.

Keywords: Juniperus occidentalis, range restoration, watershed restoration, woody biomass feedstock.

Introduction

As interest in wood-to-energy systems increases, many entrepreneurs are looking to western juniper (*Juniperus occidentalis*) woodlands as a potential source of woody biomass. Western juniper has historically been one of the most underutilized wood species in its range (Dodson et al. 2006) but one that may be well suited to energy production.

Over the last 100 years, western juniper has greatly increased its dominance throughout eastern Oregon, northeastern California, and southwestern Idaho. There are now over 6 million acres with 10% or more juniper canopy cover, of which at least one million acres have a juniper canopy cover equal to or exceeding 20% (Azuma et al. 2005). Twenty percent or more juniper canopy cover is a key indicator of loss of vegetative diversity, groundcover, rangeland health, watershed function, and wildlife habitat (Swan 1997). Many landowners, both public and private, have been implementing juniper control and eradication treatments generally designed to remove all but pre-settlement juniper stems from a site. These treatments historically consisted of chaining and bulldozing juniper (Winegar and Elmore 1977) but now focus primarily on hand cutting with chainsaws. Efforts to commercialize western juniper have occurred off and on for at least 50 years. These efforts have met with mixed results. In part, the poor success of developing juniper roundwood markets is due to perceptions about juniper's wood characteristics (difficulty in sawing and drying), low sawing recovery rates (less than 50 percent), and uncertain market potential (Dodson et al. 2006). Juniper compares favorably with other western conifers used for biomass feedstocks in terms of heat and ash content (Burke 1994). With nearly 6 million acres in juniper woodlands across Oregon, wood-to-energy may be an additional market outlet for juniper cut for watershed and rangeland restoration. However, a barrier identified in many past commercialization efforts is the cost to harvest juniper (Coulter and Coulter 2001).

Western juniper does pose some harvest system challenges. Juniper is an open-grown tree and takes on many different forms; from multi-stemmed shrubs on the driest sites to relatively tall, straight, low-taper stems on moist sites where juniper intermixes with ponderosa pine (*Pinus ponderosa*). With nearly all of these growth forms, juniper stems have tough, springy limbs that extend the entire length of the bole. These limbs pose a safety hazard when hand falling and most hand fallers will pre-limb a tree to a height of six to eight feet prior to felling (Swan 1997). Once a tree is felled, the stem will often roll on its limbs with the butt of the tree suspended

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International Journal of Forest Engineering
Volume 21, No. 1

Table 1. Production estimates for juniper harvest system components summarized from the original manuscripts.

Component	Equipment	Trial	Productive Cycle Time (minutes) – SI	Productive Cycle Time (minutes) – English	Eq.	Adj. R^2	SE (SD*)	N	Utiliz-ation
Hand Felling[1]	semi-skilled	Swan 1997	4.55	4.55	[1]		2.22*	85	
Hand Felling	professional	Dodson et al. 2006	$-0.6413 + 0.0929dbh_{si}$	$-0.6413 + 0.2359dbh_e$	[2]	0.70	0.70	347	85%
Shear	20-inch shear on International Harvester payloader	Coulter and Coulter 2001	$0.0319d_{si} + 0.0217tr_{si}$	$0.0810d_e + 0.0066tr_e$	[3]	0.26	0.41	87	97%
Feller-buncher – pure juniper stands	Timbco 445 with bar saw	Dodson et al. 2006	$0.1523 + 0.0854north + 0.0112dbh_{si}$	$0.1523 + 0.0854north + 0.0284dbh_e$	[4]	0.31	0.21	205	93%
Feller-buncher – mixed stand	Timbco 445 with bar saw	Dodson et al. 2006	$0.4530 + 4.5973ba_{si}$	$0.4530 + 0.4271ba_e$	[5]	0.14	0.37	204	86%
Manual Delimbing	semi-skilled	Swan 1997	3.03	3.03	[6]		2.02*	9	
Stroke-boom delimber – in woods	Denharco 3500 on a CAT 322B	Unpublished	$0.6327 + 0.0239d_{si} + 0.0584tr_{si}$	$0.6327 + 0.0607d_e + 0.0178tr_e$	[7]	0.33	0.76	144	83%
Pull-through Delimber	unknown loader, Dansco and CTR (unknown models)	Swan 1997	2.91	2.91	[8]		2.91*	59	
Stroke-boom delmber - at landing	Denis 3400 on a Thunderbird 736DL	Dodson et al. 2006	$1.28 + 0.46south$	$1.28 + 0.46south$	[9]		0.79*[2]	325	74% (mixed, north) 85% (south)
Mobile Delimber	shop-built	Coulter and Coulter 2001	$0.0445d_{si} + 1.8067n_p$	$0.1131d_e + 1.8067n_p$	[10]	0.36	1.28	64	89%
Delimber/ Shear Combination	shop-built	Coulter and Coulter 2001	$0.0907dbh_{si} + 0.0666tr_{si}$	$0.2304dbh_e + 0.0203tr_e$	[11]	0.21	0.80	71	77%
Skidder	unknown	Swan 1997	5.2	5.20	[12]		2.37*	14	
Skidder	CAT 518	Coulter and Coulter 2001	$2.0016op + 0.0157tr_{si} + 0.5725ns$	$2.0016op_e + 0.0048tr_e + 0.5725n_{se}$	[13]	0.67	0.88	33	92%
Skidder – Conventional	CAT 518	Dodson et al. 2006	$0.7138 + 2.5455(mixed)ns + 1.1338n_s + 0.1087{*}10^{-3}tr_{si}^2$	$0.7138 + 2.5455(mixed_e)n_{se} + 1.1338n_{se} + 0.0101{*}10^{-3}tr_e^2$	[14]	0.94	1.75	102	98%
Skidder – Mechanical	CAT 525	Dodson et al. 2006	$2.3862 + 0.0110tr_{si}$	$2.3862 + 0.0050tr_e$	[15]	0.19	1.83	48	70%
Skidder	CAT 518	Unpublished	$1.8149+0.0112tr_{si}$	$1.8149+0.0039tr_e$	[16]	0.61	1.29	53	77%

[1]In the original report, pre-limbing (mean 2.53, SD 1.90, n = 64) and felling (mean 2.02, SD 1.14, n = 21) were reported separately.
[2]Not reported in Dodson et al. 2006.

in the air, again posing a safety hazard to workers on the ground. Mechanical means to fall and delimb juniper have been tried, but may also require pre-limbing stems by hand (Coulter and Coulter 2001).

This paper will review past studies of juniper harvesting to lend guidance to those considering juniper as a woody biomass feedstock. Consistent equipment, stand, and harvest characteristics will be used to provide a fair comparison of these different studies. This comparison is needed because many of these past studies were case studies with limited or no replication and therefore extrapolation beyond the specific conditions analyzed is inadvisable. By comparing multiple case studies completed under different conditions and at different locations, managers can develop a sense for how vari-

Table 2. Variables used in production equations, where X_{si} indicates SE units, X_e English units.

Variable	Description	SI units	English units
ba_{si}, ba_e	basal area of stem ($\pi(dbh/2)^2$)	meter^2	feet^2
d_{si}, d_e	large end diameter	centimeter	inch
dbh_{si}, dbh_e	diameter at breast height	centimeter	inch
north, south, mixed	unit designations		
n_p	number of merchantable pieces per stem		
n_s	number of stems per turn		
op	operator		
tr_{si}, tr_{se}	travel distance	meter	feet

able the processes of interest are likely to be.

Methods

A literature review was conducted and one published study, two widely available reports, and one unpublished field trial of harvesting western juniper for the extraction of forest products were identified. These studies included two in south-central Oregon, U.S., near Klamath Falls (Swan 1997, Coulter and Coulter 2001), and two in central Oregon near Prineville (Dodson et al. 2006, and an unpublished field trial by Dodson and Deboodt).

Study Sites

The first documented trial of the commercial harvesting of western juniper was conducted by McNeel and Swan (Swan 1997) near Klamath Falls, Oregon. This study compared two systems: hand felling and delimbing trees in the woods followed by skidding with a rubber-tired grapple skidder; and hand felling, skidding with a rubber-tired grapple skidder, and mechanically delimbing stems at a landing using a pedestal mount pull-through delimber. All hand felling and limbing was performed by semi-skilled labor. These systems worked in a partial cut of two stands, one pure juniper and the other a mixed stand of western juniper and ponderosa pine. Only juniper stems were removed from the stands. Average diameter at breast height (DBH) of harvested trees was 34.5 cm (13.6 inches) with a mean merchantable weight of 327 kg (0.361 tons). Skidding cycles averaged 2.3 stems per cycle. All other processes averaged one stem per cycle. Only average delay-free total cycle times were reported for each process; production equations were not developed (Table 1).

The second documented trial of harvesting methods for western juniper followed up on recommendations in Swan (1997) that low-cost purpose-built equipment designed specifically for juniper may be a better option than standard logging equipment. This trial took place near Klamath Falls, Oregon, and was also a partial cut in pure and mixed stands of juniper and ponderosa pine where only juniper stems were removed. Two different harvest systems were evaluated. The first system consisted of a shear, a rubber-tired grapple skidder, and a shop-built mobile delimber. The original intent of this system was to use the shear to fell and windrow whole trees and the mobile delimber would delimb stems in the field directly onto an attached trailer. However, instability due to the design of the mobile delimber (a high center of gravity and short wheel base) resulted in the delimber remaining stationary at a central landing. The second system consisted of a custom-built delimber/shear combination similar to the Beloit Harvester manufactured during the 1960's (Drushka and Konttinen 1997) and a rubber-tired grapple skidder. The delimber/shear combination was designed to first delimb standing juniper then shear the stem from the stump. Stems required topping by hand.

Juniper stems harvested by the two systems averaged 30 cm (11.9 inches) and 230 kg (0.254 tons) for the mobile delimber and 25 cm (9.9 inches) and 153 kg (0.169 tons) for the delimber/shear combination. The rubber-tired grapple skidder averaged 1.7 trees per turn. All other processes worked on one stem at a time. Productive total cycle time equations were developed for all observed processes (Table 1).

The third documented trial of harvesting western juniper tested the use of full-scale logging equipment to harvest juniper in centeral Oregon near Prineville (Dodson et al. 2006). For this trial, two systems were tested: conventional and mechanical. The conventional system consisted of hand felling and limbing juniper by a professional timber faller followed by skidding and decking with a rubber-tired grapple skidder. The mechanical system used a bar saw-type feller buncher to fall and bunch juniper; pre-bunched turns were then skid by a rubber-tired grapple skidder. Once at the landing stems were delimbed, bucked to length, and decked using a stroke-boom delimber. Productive total cycle time equations were developed for all observed processes (Table 1).

All juniper except those stems identified as "old-growth form" was removed from treatment units. In this trial each system worked in three stands: a pure stand of juniper on a south aspect, a pure stand of juniper on a north aspect, and a mixed stand of ponderosa pine and juniper. Production was significantly different in these units for several of the processes. This difference in production was primarily due to rougher tree form (more, larger limbed and multi-stem trees) in the pure stand of juniper on a southern aspect and a heavy snow fall immediately prior to mechanical harvest of the mixed stand, which significantly impaired visibility during felling. Average quadratic mean diameter of juniper was 20.8

Table 3. Average stand conditions assumed for trial comparisons.

Variable	SI		English	
	Value	units	Value	units
DBH	30.5	cm	12	in
d	35.6	cm	14	in
t_r (between trees)	6.1	m	20	ft
t_r (skidding)	106.7	m	350	ft
n_p	1.2		1.2	
n_s	3		3	

cm (8.2 inches) across these three stands. Skidding distances averaged 110 m (350 feet) with the average skidding turn consisting of 3 stems in the conventional system and 9 stems in the mechanical system, 2.5 of which contained a sawlog.

The final study included was an unpublished field trial in central Oregon conducted in conjunction with the Camp Creek paired watershed study (Deboodt 2008). All but "old-growth form" juniper was felled by hand the winter prior to extraction activities. A stroke-boom delimber delimbed, bucked to length, and bunched those stems that were on accessible terrain and that contained a merchantable log. A rubber-tired skidder then skid pre-bunched manufactured stems to a centralized landing.

Stand Conditions

In order to compare past trials, average stand conditions were assumed (Table 3) that were within the range of stand and site conditions reported. Using Chittester and MacLean (1984) to estimate total cubic foot volume per stem and a dry density at 12% moisture content of 0.5 g/cm^3 (31 lb/ft^3), it was estimated that juniper trees in past studies were harvested at a green moisture content of approximately 65%. Therefore these values were used to estimate piece weights.

Equipment Costs

Past studies varied in how equipment costs were developed; many used prices for used equipment and none of the studies detailed how hourly rates for equipment were developed. Hourly equipment rates for this analysis were estimated following procedures and suggested coefficients from Brinker et al. (2002). Many of the machines used in the past studies under comparison are no longer produced. Therefore, currently-manufactured machine equivalents and new machine prices were used to develop machine rates. For the two shop-built pieces of equipment from Coulter and Coulter (2001), the Consumer Price Index was used to forecast equipment purchase prices to 2009 dollars. All equipment, other than chainsaws, assumed a five-year economic life (one year for chainsaws). All labor was assumed to cost $18/hour plus 50% fringe benefits.

Results and Discussion

Productive Cycle Time Estimates

Total productive cycle times were estimated for each process reviewed (Table 1) using average stand condition values (Table 3) for felling, processing, and skidding functions (Figure 1). All of these estimates are delay-free.

For felling processes, it is not surprising that mechanical felling is faster than hand felling. The one exception to this was the delimber/shear [11]. This equipment would delimb the tree standing then fell the tree using a shear. The time to fell the tree with the shear was not separated from the time to delimb the standing stem; therefore eq. [11] includes both processes in the cycle time estimation. To a lesser extent, the hand felling estimates also include some amount of delimbing on the stump. For safety reasons, the first 2-2.5 m (6-8 feet) of the bole would be delimbed prior to felling.

Both stroke-boom delimber estimates are lower than other delimbing productive total cycle times. Variation with the pull-through delimber [8] likely resulted from a combination of a small sample size, an operator learning how to use the pull-through delimber, and inherent variability in the effort required to successfully pull a juniper tree through a pedestal-mount delimber. The two shop-built delimbers [10] and [11] had the highest total productive cycle times.

The only skidding method used in the reviewed studies was using a rubber-tired grapple skidder. The difference between the estimates for total productive cycle time comes down to the felling process preceding skidding that resulted in either bunched or unbunched stems. The cycle time shown for unbunched skidding [14] may be impacted by the high correlation between skidding distance and number of stems per turn. As the skidding distance increased, the operator also increased the number of stems bunched into a single turn.

As illustrated by Figure 1, small sample sizes and low R^2 values for many of the estimated equations leads to wide confidence intervals for many of the processes. In some cases, these confidence intervals could be improved with larger sample sizes in future field studies. In other cases, for example the stroke-boom delimber from Dodson et al. (2006), 325 observations were unable to produce a reasonable relationship between observed stem characteristics (independent variables) and process time because either the wrong variables were recorded or because there is too much inherent variability in log processing times to make this correlation.

Process Costs

Equipment rates (cost per productive hour) and volume estimates were combined with total productive cycle time equations to estimate process costs in 2009 dollars per green tonne (65% moisture content). Results for felling processes are shown in Figure 2. Hand felling [2] is always cheaper than other methods. However, the assumed labor rate of $18/hour used for all machine costing is likely not commensurate with the skill level of the professional timber faller observed in Dodson et al. (2006). As discussed above, [11] includes both the falling and delimbing process, and it is therefore not surprising that $/tonne prices are higher than for other felling

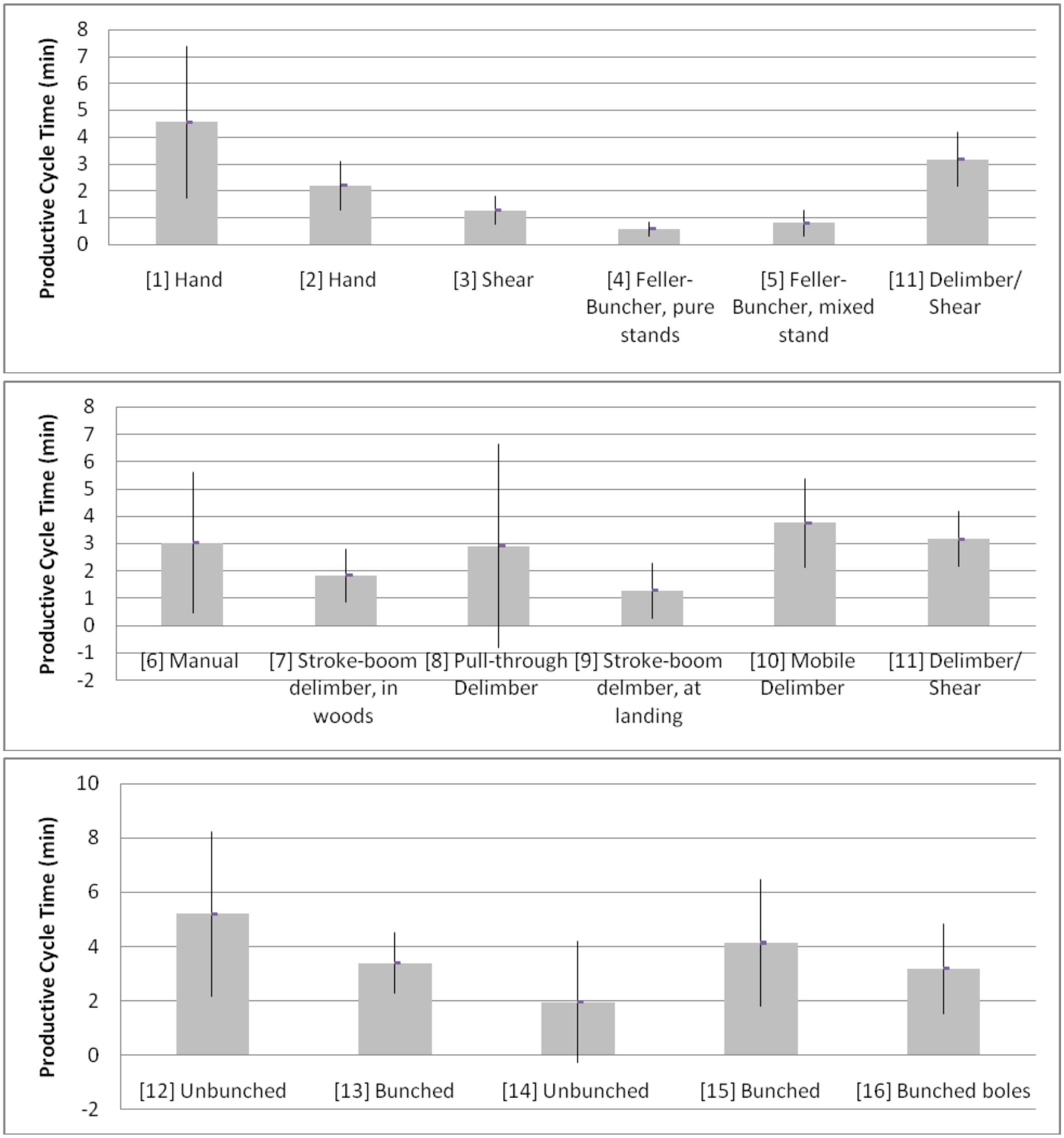

Figure 1. Comparison of total productive cycle times (solid bars) and 80% confidence intervals (solid lines) for felling (top), processing (middle), and skidding (bottom) processes. Bracketed numbers refer to the equation used to estimate cycle times.

processes.

Costs of log processing options are presented in Table 3. Manual processing is shown to be the least costly method for processing logs throughout the range of stem diameters examined, followed by a stroke-boom delimber operating at a landing for diameters greater than 30 cm (11 in) DBH. All of these estimates assume 1.2 recovered pieces per tree. While with most tree species this value should correlate well with diameter, this is not the case with juniper. Therefore, for lack of a better estimate, the number of pieces per stem was held constant across the range of diameters examined.

Skidding costs are presented in Table 4. All estimates assume three trees per turn. As stated above, the number of pieces per turn for [12] was highly correlated with skidding distance, which would result in higher $/tonne costs at shorter skidding distances and lower costs at longer skidding distances. The three estimates of skidding bunched stems agree well.

Using average stand and site variable values (Table 3), total stump to landing harvesting costs varied from a low of $35.14/tonne ($31.88/ton) for hand felling [2], skidding [14], and manual delimbing [6], to a high of $96.19/tonne ($87.26/

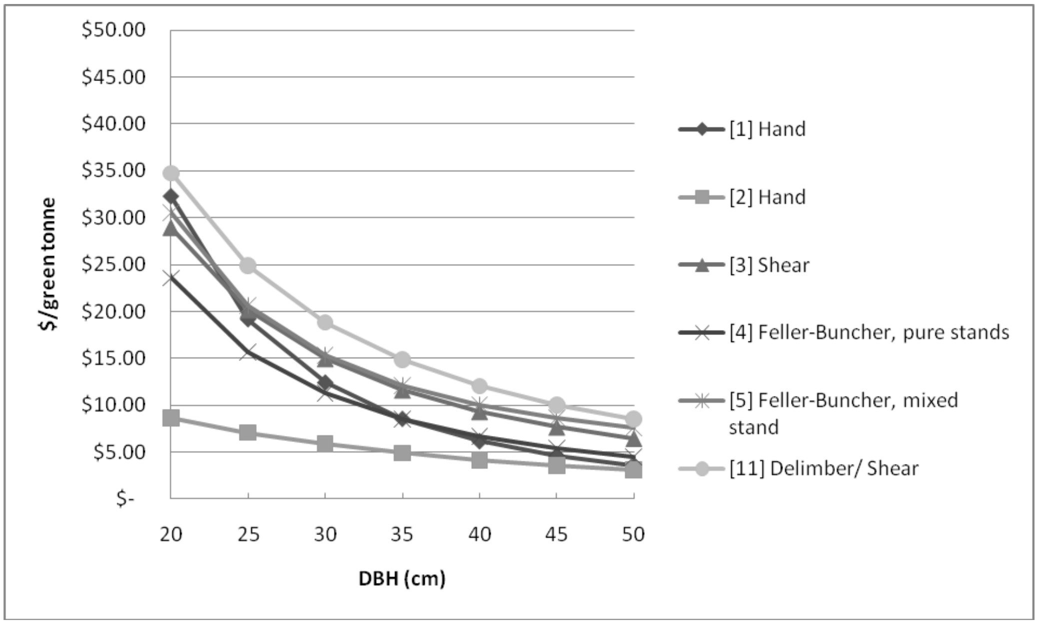

Figure 2. Cost per green ton of six felling processes based on average stem diameter.

Table 4. Machine rate variable values.

Equipment	Purchase Price	HP	Salvage	Ins.[1]	Utiliz-ation	Fuel Cons. (g/hp-hr)	Repair/ Maint.	$/SMH[2]	$/PMH[3]
CAT 525	$235,000	160	15%	5%	65%	0.0280	100%	$103.72	$159.58
Valmet 445 w/bar saw	$467,000	300	15%	4%	60%	0.0263	75%	$164.78	$274.63
Denharco 3500 on Cat 320B	$500,000	128	25%	2%	85%	0.0217	100%	$160.79	$189.16
Quadco 20" shear on non-leveling carrier	$325,000	150	50%	5%	60%	0.0217	100%	$100.06	$166.76
Danzco PT20L delimber	$40,000	0	20%	4%	85%	0.0300	65%	$10.85	$12.77
Komatsu PC220LL-8	$225,000	168	30%	2%	65%	0.0310	90%	$89.81	$138.17
Mobile Delimber	$167,000	150	25%	2%	65%	0.0300	100%	$77.31	$118.94
Delimber/ Shear	$67,000	150	25%	2%	65%	0.0300	100%	$54.67	$84.11
Hand faller	$850	4.4	25%	4%	75%	0.0568	100%	$28.58	$38.10

[1]Insurance; [2]Schedulded Machine Hour; [3]Productive Machine Hour.

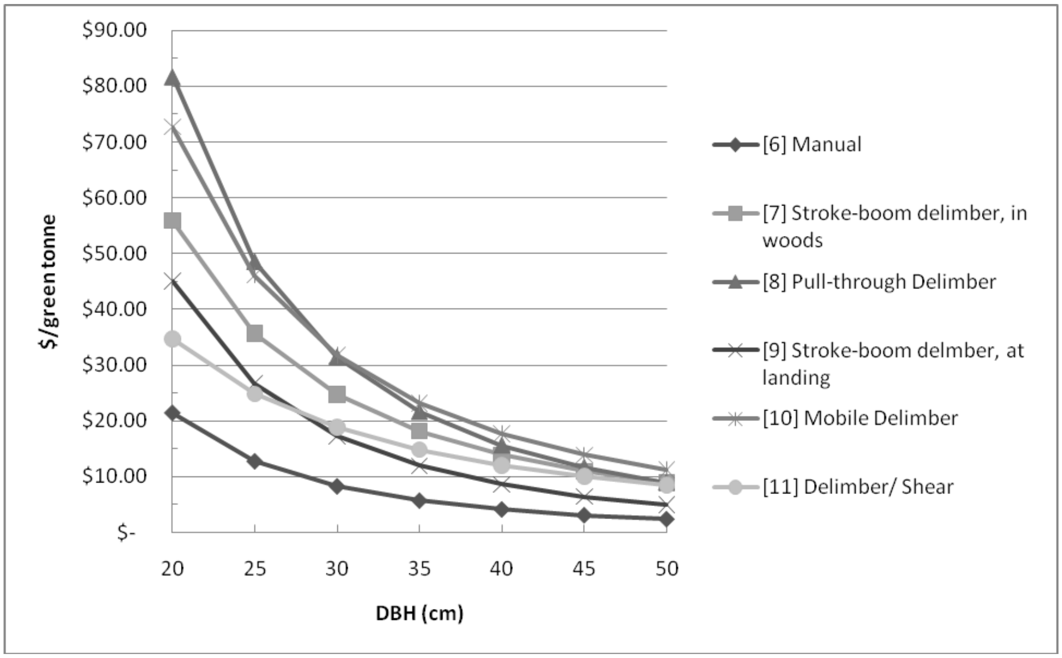

Figure 3. Cost per green ton of six log processing options based on average stem diameter.

ton) for felling with a feller-buncher in heavy snow [5], skidding [12], and the shop-built mobile delimber [10]. Average stump to landing logging system costs were approximately $74/tonne ($67/ton). Hayes and Morgan (2009) report average surveyed logging costs for ground-based mechanical whole-tree systems in northern Idaho and western Montana to be $25.53/tonne ($23.16/ton). This logging rate is 35% of the average estimated stump to landing logging costs for juniper. The primary reasons for this discrepancy are low volumes per acre, which increase bunching and skidding times, and high felling and processing times due to poor tree form, specifically large limbs and multiple stems.

The weakest link in all of these estimates is the calculation of stem volume. Because juniper is not generally considered a commercial timber species, little effort has been put into the development of volume equations. Additionally, juniper form is highly inconsistent with often poor correlation between DBH and other metrics of interest, such as height and limb size. If juniper is to be utilized as a woody biomass feedstock the issue of estimating juniper volume needs a better solution than is currently available.

A related issue is the quantification of juniper tree form. Log processing effort appears to have a higher correlation with tree form than with stem diameter. Currently no tree form classification has been developed for juniper. An accepted tree form classification could help to both calibrate volume models and would assist in more accurately predicting effort required for processes such as log processing. While none of the reviewed studies looked at whole-tree grinding of juniper (and none are known to exist in the literature), it is hypothesized that grinding effort would also correlate to tree form.

Whole-tree grinding of juniper is occurring in practice at a limited scale in central Oregon. Cost estimates for grinding juniper are circumstantial and not well understood. If juniper is to be used for a woody biomass feedstock, additional production studies are needed that look specifically at effort required to grind juniper of various sizes and forms, the costs associated with these levels of effort, volume of biomass recovered, and the transportation of ground material to an end user. The reviewed studies here give reasonable estimates for felling and skidding costs based on average stand characteristics, but grinding techniques have not been assessed.

Estimates of juniper logging costs presented here depend heavily on the production of sawlogs for several reasons. First, sawlogs are the primary product with a value great enough to justify the cost of juniper extraction. Dodson et al. (2006) suggest that juniper harvest operations be selective in which trees are processed into logs. The cost of processing small or rough-form trees has shown to be greater than the value of the logs produced, resulting in many stems left in the unit or in a pile at the landing. This is evidenced by the mechanical system in Dodson et al. (2006) where, on average, nine stems per turn were skid to the landing with 6.5 of these stems left in a slash pile. Secondly, the main goal of most juniper harvest operations is to remove juniper from the project area for watershed and range restoration purposes. Therefore the production of saleable wood products is of secondary importance and low-value material is left on site. Finally, there is little market outside woody biomass for small-diameter juniper stems. With an expansion of juniper operations for the generation of woody biomass, it is possible that costs per tonne could decrease below the rates presented here due to an increase in total tonnes produced when whole trees, rough-form stems, and small-diameter stems are included. It is also just as likely that these same tree forms that currently

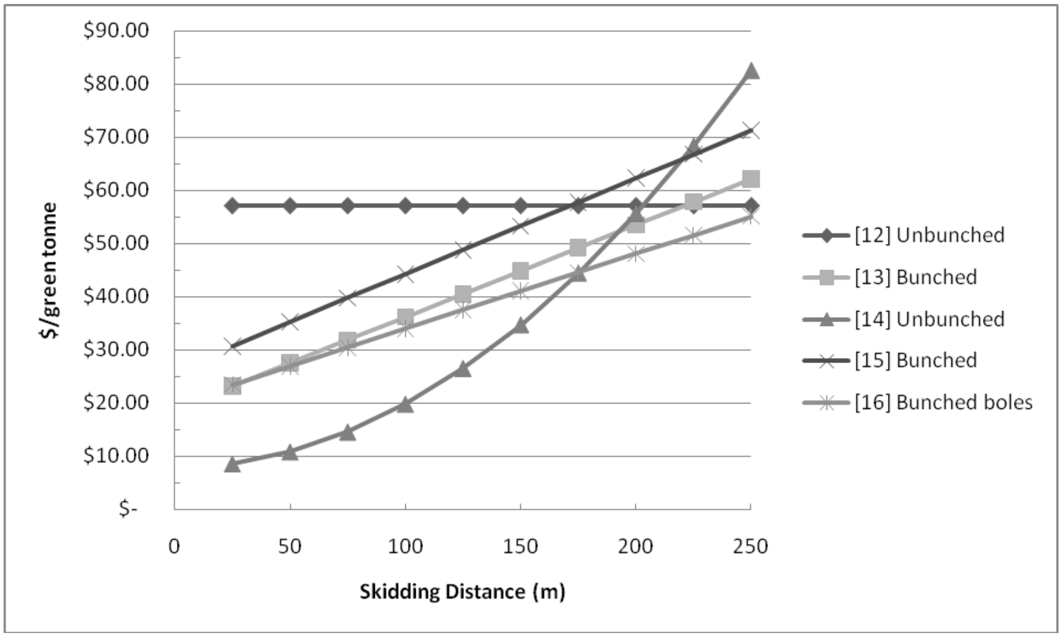

Figure 4. Cost per green ton for five estimates of skidding with various skidding distances.

are uneconomical to produce sawlogs from are just as uneconomical to grind and process into woody biomass. Further field trials are needed to address this question.

Conclusion

Standing alone each of these studies, specifically the two unpublished reports and the unpublished field trial, is of limited value due to small sample sizes and the inherent issues with extrapolating case study findings beyond the specific conditions examined. Put together, however, these results give managers reasonable estimates of western juniper extraction costs and the range of values to be expected.

Literature Cited

Azuma, David L.; Hiserote, Bruce A.; Dunham, Paul A. 2005. The western juniper resource of eastern Oregon, 1999. Resource Bulletin PNW-RB-249. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 18 p.

Brinker, R.W., J. Kinard, B. Rummer, and B. Lanford. 2002. Machine Rates for Selected Forest Harvesting Machines: Circular 296 (revised), Auburn University, Auburn.

Burke, E.J. 1994. Demonstration of the pelletizing properties and the heat of combustion of western juniper (*Juniperus occidentalis* Hook.): Final report. (September 19, 1994). Unpublished report available at http://juniper.oregonstate.edu (accessed 7/31/09). 3 pp.

Chittester, J.M. and C.D. MacLean. 1984. Cubic-foot tree volume equations and tables for western juniper. Research Note PNW-420, December 1984. USDA Forest Service. 8 pp.

Coulter, E., and K. Coulter. 2001. Western juniper harvest systems trial. Final Report to REACH, Inc. 37 p. http://juniper.oregonstate.edu/harvest01.pdf (accessed 12/15/05).

Deboodt, T. L. 2008. Watershed response to western juniper control. PhD Dissertation. Oregon State University, Corvallis. 140 pp.

Dodson, E.M, T. Deboodt, and G. Hudspeth. 2006. Production and Cost Estimates for Two Western Juniper Extraction Systems. *Western Journal of Applied Forestry* 21(4):185-194.

Drushka, K., and H. Konttinen. 1997. *Tracks in the Forest: The Evolution of Logging Machinery*. Timberjack Group Oy, Finland. 254 pp.

Hayes, S., and T. Morgan. 2009. Estimating Harvesting Costs. Poster presented at 2009 Society of American Foresters National Convention, Orlando, FL, September 30-October 4, 2009.

Swan, L. 1997. Western juniper harvest systems comparisons project. Final Report to Klamath County Economic Development Association. http://juniper.oregonstate.edu/harvest.htm (accessed 12/15/05).

Winegar, H., and W. Elmore 1978. Mechanical manipulation of western jniper – some methods and results. In: Matin, Robert E.; Dealy, J. Edward; Caraher, David L., eds. Proceedings of the western juniper ecology and management workshop; 1977 January; Bend, OR. Gen. Tech. Rep. PNW-74. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 107-119