Comparing Productivity and Costs of Two Beetle-killed Stand Harvesting Methods in Northern Colorado

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Abstract

There has been increasing interest in utilizing beetle-killed biomass for bioenergy and bio-based products in the Rocky Mountain region of the United States. However, the conventional harvesting method in the region leaves tops and limbs of felled trees on the forest floor or puts them into small in-woods slash piles for later burning, preventing collection of logging residues and non-merchantable parts of beetle-killed trees. This study was designed to introduce a whole-tree harvesting method and compare the productivity and cost of the whole-tree method with the conventional "lop and scatter" method. We conducted a detailed time study on a clear-cut operation of a beetle-killed stand in northern Colorado using the two harvesting methods. Both methods involved the same ground-based machines and operators for a fair comparison, but had a different system configuration as log processing occurred in different locations (i.e., at the stump vs. landing). The results show that the timber production costs of the two methods were \$26.93 per bone dry ton (BDT) for lop and scatter and \$24.80 BDT^{-1} for the whole-tree method. As the bottleneck machine, delimber was the main cause of the higher production cost in the lop and scatter method.

Keywords: mountain pine beetle, whole-tree harvesting, logging residues, detailed time study

Introduction

Beetle-killed trees resulting from the widespread bark beetle infestation in the Rocky Mountain region of the United States represents a vast, high-density biomass feedstock resource for bioenergy and bio-based products. Approximately 1.37 million hectares of coniferous forests in Colorado have been affected by eruptive populations of bark beetle since 1996 (Colorado State Forest Service 2016). Using biomass for bioenergy from the widely available resource of dead pines in the region has become a topic of interest for land managers, but there exist many uncertainties with respect to the harvest of dead trees and their utilization.

In Colorado, a "lop and scatter" method has been widely used for salvage harvest of beetle-killed trees (Matonis et al. 2014). In the method, delimbing and bucking occur at the stump, resulting in tops and limbs being left on the forest floor. This slash retention prevents collection of logging residues for utilization for bioenergy or bio-based products. A whole-tree harvesting method may

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be an alternative option for beetle-kill salvage harvest, which allows for the collection of logging residues at the landing without additional biomass collecting process. Compared to lop and scatter, the whole-tree method could improve delimber efficiency as the machine does not need to move around between log piles in the harvest unit. However, a relatively low productivity in primary transport of whole trees could lead to a higher harvesting cost especially when a system productivity is highly influenced by a long skidding distance (Han et al. 2004, Adebayo et al. 2007).

There has been an information gap about the productivity and costs of beetle-kill salvage harvest, as well as how stand and operational conditions affect the productivity of the two harvesting methods. This study was aimed to analyze and compare the two beetle-kill salvage harvesting methods for their productivity and costs through a detailed time study. In collaboration with the Colorado State Forest Service and our industry partners, we applied the two methods side by side on the same beetle-killed forest stand located in the Colorado Forest State Park. Our detailed methods and study results are presented below.

Methods

Study site and harvesting methods

A 10.1-acre lodgepole pine (*Pinus contorta*) stand was selected as our study harvest units. The stand is located in the State Forest State Park in northern Colorado (40°57´N, 105°98´W), and has been infested by the mountain pine beetle since 2008. The stand located on a relatively flat terrain was divided into two approximately equal size harvest units for side-by-side application of the two harvest methods: lop and scatter, and whole-tree harvesting (Figure 1). The units were cruised prior to harvesting using a systematic sampling method with a 5% of sampling intensity. Trees larger than 5 inch diameter at breast height (DBH) and their individual mortalities were recorded and used to describe pre-harvest stand characteristics (Table 1).

Table 1. Stand characteristics of the study harvesting units.

Characteristics	Harvesting unit	
	Lop and scatter	Whole-tree harvesting
Area (ac)	5.3	4.8
Mean DBH (in)	8.8	8.8
Mean height (ft)	60.1	64.2
Average basal area (ft^2/ac)	145.0	150.6
Trees per acre	331	350
Mortality (%)	39.5	47.3

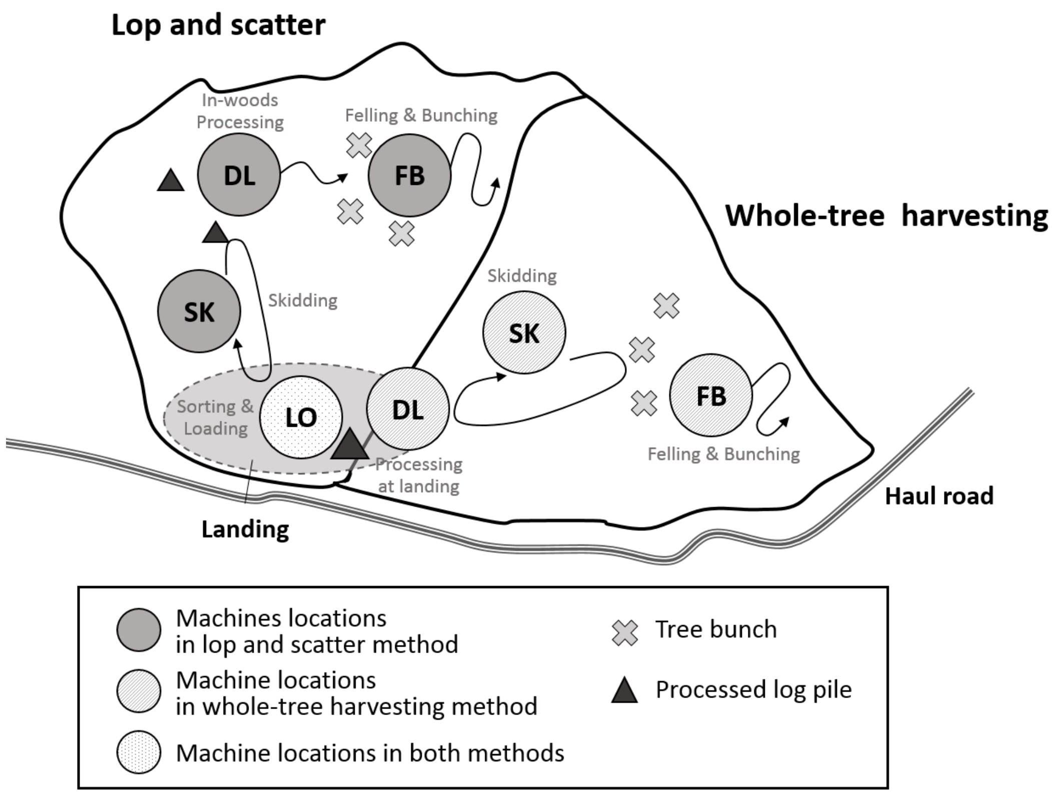

Figure 1. A map of the study harvest units showing harvesting machines and processes involved in each harvesting method.

Each unit was clear-cut with the same ground-based machines and operators for a fair comparison, but had a different system configuration as log processing occurred in different locations (i.e., at the stump vs. landing). In the lop and scatter method, a TimberPro TL-735-B feller-buncher was used to cut and bunch trees at the stump. Two Timberline SDL2 stroke delimbers then top, delimb and buck trees prior to primary transport (skidding) of logs carried out by a Tigercat 615C skidder (Table 2). In the whole-tree method, the skidder brought whole-trees to the landing where delimbers process the trees while creating slash piles at the landing. For both methods, a Barko 495ML Magnum loader was used to sort and load logs onto log trucks.

Table 2. Harvesting equipment purchase prices, utilization rates and machine rates used in the study.

Machine (make/model)	Purchase price	Utilization rate[a]	Machine rate
	($)	(%)	($/SMH[b])
Feller-buncher (TimberPro TL-735-B)	395,000	60	134.04
Stroke delimber (Timberline SDL2)	355,000	65	114.69
Skidder (Tigercat 615C)	219,000	60	90.97
Grapple loader (Barko 495ML Magnum)	205,000	65	79.26

[a] Adapted from Brinker et al. (2002)
[b] Scheduled machine hour

Data collection and analysis

Detailed time study data were collected to estimate machine productivity and costs using standard work study techniques (Miyata 1980, Olsen et al. 1998, Brinker et al. 2002). Delay-free cycle times for each machine were recorded using stop watches. Independent variables hypothesized to have an influence on machine productivity were also measured and recorded for each cycle (Table 3). Predictive equations were developed using ordinary least squares regression techniques. Travel distances of feller-buncher were estimated by ocular measurement. The empty travel and loaded travel distances of skidder were measured using GPS receivers (Columbus VGPS-900) mounted on the skidder.

For the feller-buncher cycle time equation, we merged data from both units to develop a single cycle time regression equation as there was no difference in feller-buncher operations in both units. However, we developed separate equations for delimber cycle times because the lop and scatter method required the delimber to move from pile to pile, whereas the delimber stayed at the landing in whole-tree harvesting. An indicative variable was used to identify the delimber movement in each cycle for lop and scatter (Table 3). Two different cycle time equations were also developed for skidding operation as the skidder handled a different type of product (i.e., processed logs vs. whole-trees) in each method. For loader cycle times, we developed a single cycle time equation for both methods with an indicator variable for two different activities (0 = sorting, 1 = loading). All statistical analyses were conducted in R software (R Development Core Team 2014), and values of $P < 0.05$ were considered to be statistically significant.

The amount of production was normalized to bone dry tons (BDT) by applying a wood density of 0.41 BDT per m^3 (Miles and Smith 2009) to the average log volume estimated from field data samples. Using the average cycle time and the average production per cycle, machine productivity was estimated in BDT per scheduled machine hour (SMH). A bottleneck machine was identified, and the entire system productivity was determined using the bottleneck productivity, assuming all the machines work simultaneously in a ‘hot’ operation.

Results

Table 3 shows delay-free cycle time regression equations developed for individual machines involved in the two harvesting methods. For feller-buncher, the number of standing trees including both live and dead, the number of downed dead trees, and travel distance of machine per each cycle are significant predictors for the machine cycle time. There were no effects of tree mortality between standing live and standing dead trees on feller-buncher cycle times, but handling downed dead trees has a significant effect on cycle times. For delimbers, both the number of live and dead trees are significant predictors of the cycle time and it appears that it takes relatively less time to process dead trees than live trees in both methods. In the lop and scatter unit, the number of logs, and empty and loaded distances are significant variables in the regression model. In whole-tree harvesting, loaded distance is a significant variable. The number of logs and activities are significant predictors of cycle time for grapple loader.

Table 3. Delay-free cycle time (minute) regression models for feller-buncher, delimber, skidder, and grapple loader used in lop and scatter and whole-tree harvesting.

Machine	Parameter	Estimate	SE	*t*	*Pr*	Model adj. R^2
Feller-buncher	Intercept	8.866	0.646	13.73	<0.01	0.4707
	No. of standing trees	4.207	0.311	13.54	<0.01	
	No. of downed trees	14.229	0.931	15.28	<0.01	
	Travel distance (ft)	0.307	0.023	13.36	<0.01	
Stroke delimber	Intercept	32.089	2.116	15.16	<0.01	0.3369
(lop and scatter)	No. of live trees	5.999	1.261	4.76	<0.01	
	No. of dead trees	4.754	1.774	2.68	<0.01	
	Move and reposition (MR)	29.184	2.486	11.74	<0.01	
Stroke delimber	Intercept	32.183	1.493	21.551	<0.01	0.1693
(whole-tree harvesting)	No. of live trees	5.723	0.825	6.938	<0.01	
	No. of dead trees	5.294	0.971	5.452	<0.01	
Skidder	Intercept	54.787	21.972	2.49	<0.05	0.7295
(lop and scatter)	No. of logs	2.491	1.043	2.39	<0.05	
	Empty distance (ft)	0.076	0.019	4.00	<0.01	
	Loaded distance (ft)	0.202	0.050	4.04	<0.01	
Skidder	Intercept	5.952	64.725	0.09	0.93	0.5271
(whole-tree harvesting)	No. of trees	1.796	1.763	1.02	0.32	
	Empty distance (ft)	0.163	0.126	1.30	0.21	
	Loaded distance (ft)	0.236	0.104	2.28	<0.05	
Loader	Intercept	23.939	1.958	12.228	<0.01	0.1801
	No. of logs	3.430	0.482	7.120	<0.01	
	Activity type	9.248	1.895	4.881	<0.01	

The standardized cycle times estimated using the cycle time regression models show that feller-buncher and grapple loader have the same productivities in both methods (Table 4). However, the productivity of two delimbers used in both methods is different. The productivity of delmber in the lop and scatter method is 20.68 BDT of timber per SMH, 8% lower than that in the whole-tree method mainly due to frequent movements of machine in the lop and scatter method. Another difference in individual machine productivities in the two methods occurs during skidding operation. The productivity of skidder is 25.74 BDT SMH^{-1} for the lop and scatter method, whereas the trees are transported to the landing at a rate of 25.07 BDT SMH^{-1} in the whole-tree method. Delimber is turned out to be the bottleneck machine in both methods.

Assuming that the two harvesting methods are applied as a ‘hot’ operation, the unit cost of timber production is \$24.80 BDT^{-1} in the whole-tree method, which is 8% lower than the lop and scatter method. This difference is mainly caused by a higher productivity of delimber in the whole-tree method (Table 4).

Table 4. Productivity and costs of the lop and scatter, and whole-tree harvesting methods

Configuration/machine	Machine		System	
	Productivity	Cost	Productivity	Cost
	(BDT SMH^{-1})	(\$ BDT^{-1})	(BDT SMH^{-1})	(\$ BDT^{-1})
Lop and scatter				
Feller-buncher	27.76	4.83	20.68	26.93
Stroke delimber*	20.68	5.55		
Skidder	25.74	3.53		
Grapple loader	26.31	3.01		
Whole-tree harvesting				
Feller-buncher	27.76	4.83	22.45	24.80
Skidder	25.07	3.63		
Stroke delimber*	22.45	5.11		
Grapple loader	26.31	3.01		

* Estimated for two delimbers

Conclusion

Our detailed time study on beetle-killed stand harvesting in northern Colorado suggests that downed dead trees may significantly increase feller-buncher cycle times compared to standing trees. On the contrary, processing dead trees using a stroke-delimber appears to take slightly less time than processing live trees. Our comparisons of the conventional lop and scatter method with whole-tree harvesting in the study harvest units indicate that whole-tree harvesting could be more cost-effective in timber production while allowing for the collection of logging residues at the landing. Major differences in productivity occurred during delimbing and skidding. This potential gain from whole-tree harvesting by lower costs may help improve the economic feasibility of utilizing low value forest residues for bioenergy and bio-based products. Future studies should further analyze the potential gains and losses in applying whole-tree harvesting under a wide variety of stand and operational conditions.

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