DRAFT Subject to Peer Review and Revision (9/29/04)

Report on the ASV Small Parcel Fuel Reduction Demonstration - year 2003

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Grant Source and Number: USDA Forest Service Economic Action Program,
01-DG-11051150-021

Introduction

Catastrophic wildfires have become an increasingly serious threat to forests and communities in the western United States, especially in California. The effective fire-suppression policy of the past decades has resulted in an enormous fuel accumulation that must eventually cycle – often through a catastrophic fire.

The only way to prevent that from happening is to treat the fuel in appropriate ways, so that an eventual fire can be controlled and kept within the boundaries of its sound ecological role.

Fuel treatment consists of simple removal, spatial redistribution or a combination of the two. Cost-effective fuel treatment can be performed mechanically with appropriate machinery that can also include a wood harvesting operation. Through the fuel treatment overstory trees are spaced by selective thinning, while the understory is diminished or removed together with any ladder fuel that would help a fire climb from the ground to the tree crowns.

Another possible goal and benefit of fuel reduction is ecologically-based forest restoration. In many of the forests of the west several natural fire cycles have been missed. The consequence of the missed low intensity fire exposure is more trees per acre that are less than 90 years of age and a different species composition that includes more shade tolerant species. There may be several hundred smaller shade-tolerant trees now where there were perhaps less than one-hundred larger diameter, shade intolerant and fire resistant trees when the natural fire regime existed.

Although not profit-driven, the harvesting component is crucial to offsetting the cost of the entire operation, at least in part. Reducing the cost of fuel treatment is particularly important, because it allows extending the treated area beyond the economical limits of a cost-only activity, supported by limited funds.

Fuel reduction treatments are especially urgent near homes, where a catastrophic fire would also endanger property and human lives. Here, one must create a minimum defensible space that would enable firefighters to operate safely and effectively. Otherwise evacuation would be the only alternative.

However, the forested properties associated with homes are often too small for cost-effective fuel treatment, performed with traditional methods and equipment. The amount of product obtained from such a thinning seldom justifies hiring a forester to develop a harvest plan and moving heavy equipment to the site. Small parcel owners need a different solution, which this project has suggested and tested.

Goal

The goal of the project was to test an alternative approach to fuel treatment that may respond to the needs of small-parcel owners. The project explored innovative ways to cope with the two main constraints encountered under such conditions, i.e. the inefficiency of preparing a harvest plan and of moving heavy machinery to sites that would not yield enough wood to offset these costs.

The California Forest Practices Act requires the preparation of a timber harvest plan if commercial products are removed. Timber harvest plan development is costly and not practical for parcels that are less than 10 acres. However there are timber harvest plan exemption options available that may enable a landowner to remove the products of the fuel reduction treatment. The most appropriate exemptions are a) those for removing hazardous fuels from within 150 feet of a residence and b) removing less than 10 percent of total volume.

Timber harvest plan development is not necessary if the owner keeps the wood for his/her own use, neither selling it nor bartering it. Therefore, the alternative system proposed was geared to produce lumber of recognizable value, ready for use and able to match the individual needs of the forest owner. A mobile small-log sawmill was integrated into the project to produce cants and boards of variable size according to the specifications provided by each property owner. An Economizer mobile sawmill from the Watershed Training and Research Center in Hayfork, California was used.

Secondly, an alternative to standard heavy timber harvest machinery was used by adopting a small rubber-tracked skid-steer base machine designed by ASV[1] Inc. and specially modified for forestry operations by Davco Mfg. The machine can provide all the functions of a complete harvesting system, since the base tractor can alternatively carry a feller-buncher saw, a tree processor head, a brush cutting head for mastication or a log-grapple. All of the equipment can be transported on a trailer pulled by a heavy pick-up truck, which makes for faster, economical moving between sites. The company selected for the project was Harvest and Landscape Ltd., based in Sherwood, Oregon.

An operation based on equipment such as the ASV system and the Economizer sawmill may respond to the needs of small parcel owners, as it allows them to avoid the two major cost items of a typical mechanical thinning operation. However, since they are lighter and less sophisticated, both machine systems are inherently less productive than the ones that they replace. The research part of the project focused on quantifying the reliability and the productivity of both machine systems, in order to estimate the actual costs associated with their use under small parcel conditions.

The Demonstration

The demonstration was conducted from March 28 to October 24, 2003 on 9 sites, selected from a much larger pool inspected and characterized during the previous year. These 9 sites were considered representative of many of the operational conditions encountered in the small parcels of the Northern Sierra. The distribution of sites is illustrated in Figure 1. A brief description of the sites is reported in table 1.

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Figure 1. Site location map.

The average area treated per site was 3.2 acres, with a minimum of 0.9 and a maximum of 7.3. All sites had been surveyed and cruised, and trees selected for removal had been marked with paint. An average of 245 trees were harvested on a each site, yielding approximately 920 cubic feet of millable sawlogs. The Blairsden site in Plumas County was a combination of two separately owned parcels. This explains why this demonstration site was so much larger than the others.

Except for YUB1, all stands apparently resulted from natural regeneration after logging or fire. Mixed conifer stands were the most common, presenting variable mixes of Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*) and incense cedar (*Calocedrus decurrens*). Two of the parcels were essentially pure ponderosa, with occasional incense cedar. One of them – YUB1 – was a plantation, established on terraces that once constituted the timber yard of a sawmill. In all cases, the thinning removed 20 to 30 % of the basal area.

Table 1 – *Description of the Test Sites*

Site	Unit	NEV1	NEV2	PLU2&3	PLU4&5	SHA1	SHA2	SHA3	SIE1	YUB1
Community		San Juan Ridge	Nevada City	Blairsden	Cromberg	Shingletown	Shingletown	Shingletown	Loyalton	Camptonville
County		Nevada	Nevada	Plumas	Plumas	Shasta	Shasta	Shasta	Sierra	Yuba
Acreage	Ac	3.8	3.4	7.3	4.3	0.9	2.0	2.6	1.8	2.7
Slope	%	14	18	12	20	10	2	2	14	10
Species		Mixed conifer	Mixed conifer	Mixed conifer	Mixed conifer	Mixed conifer	Mixed conifer	Mixed conifer	Ponderosa	Ponderosa
Harvest (Total)	trees	185	106	775	284	144	142	118	336	210
Harvest (Total)	cu.ft	838	493	2593	1050	640	606	403	841	812
avg. tree volume*	cu.ft	4.5	4.6	3.4	3.7	3.7	4.3	3.4	2.5	3.9
avg. DBH*	In	6.5	6.4	5.3	6.4	5.8	7.0	6.8	5.9	5.8
avg. height*	Ft	47.9	45.1	N/A	33.4	43.3	37.6	37.0	32.4	36.9

* Average figure obtained from the cycles sampled, as in table 2

The trial was conducted in two stages at each site: in-stand operations with the ASV, followed by milling of the sawlogs with the Economizer.

First, the ASV was moved to the site, unloaded and operated until all the trees selected for removal had been cut, all the sawlogs had been moved to a landing and all the non-merchantable trees and the tops and limbs had been masticated. Generally, the work would begin with mastication, aimed at reducing all the undergrowth and the trees smaller than 4 inches diameter at breast height (DBH).

The ASV would then switch implements, installing the tree cutter to fell all marked sawlog trees. After completing the felling, the ASV would drop the saw and pick up the tree processor, so that all cut trees could be delimbed and bucked into appropriate lengths, according to the owner's requirements. When processing had been completed, the ASV would again switch implements, attaching the log grapple and skidding all logs to a landing that could be reached by the sawmill. Finally, the ASV would again attach the masticator and treat all the slash generated during tree processing. All equipment would then be loaded onto the trailer and moved to another site. On two sites – PLU 2&3 and YUB1 – the trees were taken to a landing and chipped, rather than converted into sawlogs, therefore, delimbing and bucking was not performed here. In these two cases, potential sawlog yield was estimated using appropriate volume tables, rather than scaled.

This general routine was sometimes modified slightly according to the site, with the intent of maximizing work efficiency. All the work was performed by the same operator.

After the ASV had completed a few sites, the Economizer mill would follow. The sawmill was accompanied by a small skid-steer loader, necessary for sorting the logs and moving them from the stacks to the log infeed. As the sawmill arrived on site, the log deck would be unloaded and the sawmill set up. If necessary, sorting would follow.

Then sawmilling would start, generally lasting a few hours. Finally, the sawmill would be dismantled and loaded, and the operation moved to a new site. The work was conducted by two operators, who would assist each other while sorting with the skid-steer loader and then position themselves respectively at the log deck and at the green chain when sawing the logs.

This report describes the study conducted on the ASV only. A separate report will be produced for the Economizer mill.

Materials and Methods

The research part of the project consisted of a time-motion study that quantified the productivity of both machines. Time recording was conducted on a non-stop basis, classifying time consumption for each activity according to functional categories, including delays. This enables the assessment of the reliability of the machinery as well as the efficiency of the system. All product outputs were also recorded.

Log productivity was estimated on the basis of the ASV's on-board log counter readings, after calibrating them with frequent sessions of direct recording – i.e. counting the logs produced in a given time unit and comparing that count with that shown by the on-board counter. The log count would be converted into a tree count and a total volume by respectively applying the average number of logs per tree and the average log volume obtained by direct measurements performed by the researchers. As an average, half of the trees with millable logs that were felled and processed were scaled, using a tree caliper and logger's tape. This also allowed checking the accuracy of the measuring system mounted on the processor.

The total time recording was completed by individual timing the sessions with a clock-equipped computer, performed on a representative number of cycles for each of the following activities: felling, processing and skidding. For this purpose, identification numbers were painted on selected trees representing the range of size and species encountered on each site. Then the ASV was timed while felling the trees, breaking down the time for each cycle (i.e. one tree) into cycle element categories. The ASV would again be timed while processing the same numbered trees, using a similar cycle-element approach. All logs produced from each tree were marked with code-numbers and later scaled. Skidding was timed with the same method, but here a cycle consisted of a turn, not a tree. The load size was estimated by counting the number of logs and applying the average log volume for the site. Skidding distance was either paced or measured with a hip chain depending on the situation. Sample size for each activity and site is reported in table 2. Approximately 50 percent of the total work cycles were timed. Detailed time and motion studies of this type allow relating machine performance to tree and terrain characteristics, which is very useful when trying to predict operational productivity – and then harvesting cost – under variable conditions.

All timing was conducted using Husky Hunter hand-held all-weather computers, running the dedicated Siwork 3 time-study software.

Appendix A provides a full description of all time elements by activity.

Table 2 – *Sample size for detailed stopwatch timing of each major ASV activity*

		Sample					
Site	Tot.Trees	Felling	%	Processing	%	Skidding	%
SHA3	118	46	39	47	39.8	118	100
SHA2	142	77	54.2	88	62	31	21.8
SHA1	144	0	0	55	38.1	0	0
PLU 2&3	775	537	69.3	NA	NA	506	65.3
PLU4&5	284	69	24.3	95	33.5	53	18.7
NEV1	185	74	40	135	73	0	0
NEV2	108	100	92.6	108	100	108	100
YUB1	210	152	72.4	NA	NA	205	97.6
SIE1	336	193	57.4	223	66.4	99	29.5
Total	2,302	1248	54.2	751	49.2	1120	48.7

Results

The total time expenditure recorded for the ASV during the study amounts to over 329 hours, excluding meal time – i.e 41 full 8-hour workdays. This figure includes work time, moving time, maintenance and the time spent going to a shop to obtain parts or to conduct repairs that could not be performed on site. It does not include lunch breaks and demonstration activities – such as three entire demonstration days and the occasional time spent talking to visitors to the test sites.

Table 3 lists the total time expenditure according to the activity performed, while table 4 presents the information by site.

The average time required by site is highly variable, due to site topography, tree density, travel distance to the site and the erratic occurrence of breakdowns. In order to develop more precise figures, the analysis was also run on the productive work time only – i.e. work excluding moving to site, repairs and workshop time. With this approach, productivity figures cluster more tightly and are mostly between 5 and 10 hours per acre.

Table 3 – *Total time consumption by activity*

Activity	**hours**	**% total**
Load	15.3	4.6
Travel	16.3	5.0
Unload	11.9	3.6
Reconnaissance	7.2	2.2
Implement change	14.7	4.5
Service	10.9	3.3
Repair-ASV	10.3	3.1
Repair-Implement	5.7	1.7
Shop trips	26.0	7.9
Masticate	54.8	16.6
Fell	37.7	11.5
Process	40.9	12.4
Skid	62.7	19.1
Other work	14.8	4.5
Grand total	**329.1**	**100.0**

Table 4 – *Time consumption by site*

Gross time (incl. Moving and Breakdowns)					
Site	Acres	Cu.ft	hours	hours/ac	cf/hour
NEV1	3.8	838	54.1	14.2	15.5
NEV2	3.4	493	24.5	7.2	20.1
PLU2&3	7.25	2593	46.4	6.4	55.8
PLU4&5	4.3	1050	56.5	13.1	18.6
SHA1	0.9	533	38.4	42.7	13.9
SHA2	2.0	606	25.4	12.7	23.8
SHA3	2.6	403	19.7	7.6	20.5
SIE1	1.8	841	47.4	26.3	17.7
YUB1	2.7	812	20.1	7.4	40.4
Average				15.3	25.2

Productive work time only (excl. Moving and Breakdowns)					
Site	Acres	Cu.ft	Hours	Hours/ac	Cf/hour
NEV1	3.8	838	30.5	8.0	27.5
NEV2	3.4	493	18.2	5.4	27.1
PLU2&3	7.25	2593	39.2	5.4	66.2
PLU4&5	4.3	1050	45.8	10.6	22.9
SHA1	0.9	533	26.3	29.3	20.2
SHA2	2.0	606	19.3	9.6	31.4
SHA3	2.6	403	17.3	6.6	23.3
SIE1	1.8	841	32.1	17.9	26.2
YUB1	2.7	812	14.9	5.5	54.7
Average				10.9	33.3

The higher times per acre occurred on those sites that were more dense in terms of trees per acre, such as SHA1, or where the ASV also had to sort logs as was the case at SIE1. Table 4 also reports overall productivity in cubic feet per hour, which is not a measure of actual performance – since this figure also includes the time spent on mastication - but rather an aid in estimating how wood harvesting can help offset treatment cost. Overall, the volume productivity on sawlog operations commonly varied between 25 and 35 cubic feet per hour, depending on the intensity of the thinning. Treatments removing more wood per acre allowed for higher productivity, because the non-productive mastication process had less influence. Chipping whole trees instead of converting them into sawlogs sped up the operation considerably, by eliminating the in-wood processing and the post-harvest mastication run, and by increasing the sizes of the turns that were skidded: as a result productivity doubled (PLU 2&3, YUB1).

Figures 2 and 3 provide a visual representation of the activity breakdown, respectively including and excluding moving times. Productive time was 64 percent of total time and 74 percent of the time on site. Repair and maintenance accounted for 16 % of the total time, or 18 % of the time on site. Half of this time consisted of going to a workshop to obtain spares or get repair jobs done. Therefore, the situation can be significantly improved by acquiring most necessary spares and tools, which were not always available during the trial. Fitting the truck with a welder and a lift crane and loading it with a good assortment of spares is highly desirable.

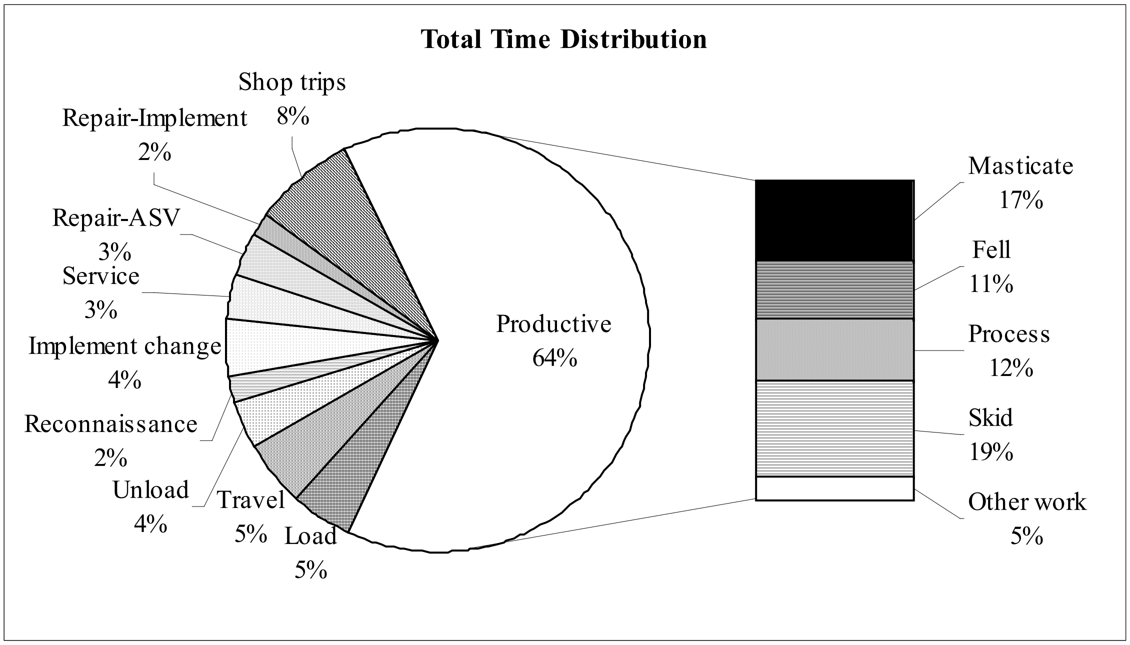


Figure 2 – *Activity breakdown – moving times included.*

Loading and unloading required more time than is typically required because of the very wet weather conditions experienced during the project. The average loading time is heavily influenced by two loading sessions that took place under heavy snow on a new trailer with a wood surface that had not been fitted with anti-slip grates. Under these conditions the rubber-tracked ASV repeatedly slipped while attempting to climb the ramp, so loading all the implements and the prime mover took up to 3 hours. After the grates were installed, or when the weather was more favorable, loading would take 1 to 1.5 hours. For most cases, moving times may be calculated as follows:

1.20 hours for loading + move distance, mi. / 31 mph + 1 hours for unloading

Switching implements was comparatively fast, taking slightly over 15 minutes for each change as an average. This value was heavily weighted by the long time required for the processor head that did not mount on the quick-attach coupler on the ASV. The manufacturer of the processor head determined that the standard ASV quick-attach coupler was not strong enough to safely hold the processor. Instead, every time the processor was installed, the quick-attach coupler was removed and the tree processor was attached directly to the ASV lift arms. This required about 20 minutes. Otherwise, switching implements provided with a quick-attach bracket would normally take less than

10 minutes. The processor head manufacturer has communicated that the new ASV versions have stronger quick-attach couplers and that any processor produced for these new versions would fit right into the quick-attach scheme.

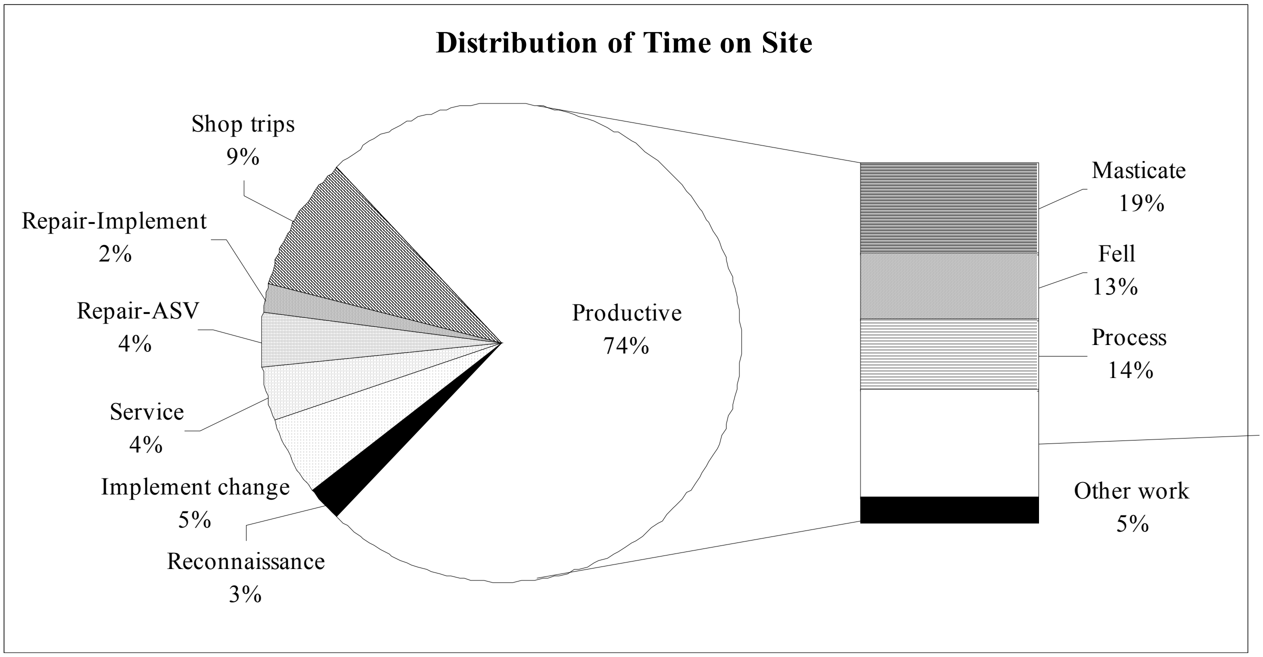


Figure 3 – *Activity breakdown – worksite time only*

If all these measures had been taken, the time available for productive work could have been substantially increased, reaching 69 % of the total scheduled time, including moving.

Figure 3 shows the distribution of productive work time among different thinning tasks: felling, mastication, tree cutting, tree processing and skidding. The "Other" category includes miscellaneous tasks related to production, such as the occasional delimbing of large trees with a pull-through delimber and some earth-moving done with the gravel bucket in order to facilitate access to the site for the mill.

Skidding took the most time, followed by mastication which represents approximately one quarter of the productive work time. Processing was the third longest task, followed by felling. These findings may direct optimization efforts, especially if one matches them to the productivity figures reported in Table 5.

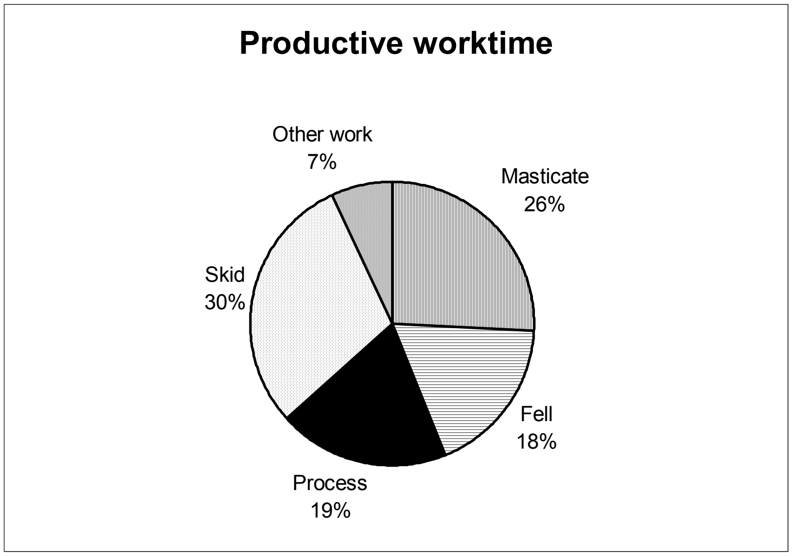


Figure 4 – *Distribution of productive work time among the different tasks.*

Table 5 reports productivity by activity and site, as calculated according to two different methods: a) dividing the total output by the total time spent in each activity and, b) dividing the average cycle output by the average cycle time, as recorded during the individual timing sessions. The two values so obtained are defined respectively as Gross productivity and Net productivity, because the former includes all minor delays that could not be isolated when recording total activity time. The individual timing sessions allowed for excluding such delays from actual productive time, so that productivity figures are based on Net productive time, with no delays.

Therefore, Gross productivity is generally less than Net productivity. On two sites – SHA2 and SIE1 – the opposite was true for skidding. This is probably due to the individually timed turns being concentrated in a specific sub-area, rather than being distributed evenly over the whole site. For this reason, in some instances, the average skidding distances for the samples may have differed from the average skidding distances for the whole parcels, and therefore the two productivity figures may represent different working conditions. Generally, Net productivity is conceptually higher than Gross productivity and the average Gross-to-Net ratio is 0.80 for felling and processing and 0.85 for skidding

Felling

Analysis of table 5 provides important information. If the first site (SHA1) is excluded where the ASV operator was getting acquainted to the relatively different site conditions (he had worked on somewhat different stands previously), we can say that the ASV can fell and bunch between 80 and 90 trees per hour in terms of Net time. Under very favorable conditions, such as those encountered at the YUB1 site, as many as 120 per hour can be felled and bunched: the YUB1 site was a pure pine plantation, with comparatively short trees, growing on flat terraces and almost aligned.

Table 5 – *ASV productivity by activity and site*

Site	Units	Fell		Process		Skid	
		Gross Productivity	Net Productivity	Gross Productivity	Net Productivity	Gross Productivity	Net Productivity
NEV1	Trees/hour	69.5	91.3	30.0	38.4	53.3	NA
	Cu.ft/hour	356.2	481.7	135.9	174.2	241.7	NA
NEV2	Trees/hour	80.5	81.5	28.3	33.6	28.6	32.6
	Cu.ft/hour	374.1	393.1	131.4	156.0	133.1	150.2
PLU2&3	Trees/hour	52.7	66.5	NA	NA	39.1	55.8
	Cu.ft/hour	176.4	222.6	NA	NA	130.9	189.7
PLU4&5	Trees/hour	69.1	86.0	42.1	45.8	26.8	48.6
	Cu.ft/hour	249.3	309.5	156.3	170.1	99.0	179.8
SHA1	Trees/hour	NA	NA	27.6	36.9	37.6	NA
	Cu.ft/hour	NA	NA	122.6	135.3	167.1	NA
SHA2	Trees/hour	54.2	84.2	28.5	37.6	32.1	23.6
	Cu.ft/hour	231.6	365.5	121.6	160.5	137.1	101.3
SHA3	Trees/hour	52.1	61.6	23.9	36.3	46.6	76.8
	Cu.ft/hour	177.9	209.9	81.7	124.1	159.2	261.1
SIE1	Trees/hour	69.8	87.9	40.0	53.9	32.0	29.8
	Cu.ft/hour	174.7	217.9	100.1	135.0	80.1	74.5
YUB1	Trees/hour	120.0	126.6	NA	NA	64.0	72.5
	Cu.ft/hour	463.8	489.1	NA	NA	247.2	282.7
Average	Trees/hour	***71.0***	***85.7***	***31.5***	***40.4***	***40.0***	***48.5***
	Cu.ft/hour	***275.5***	***336.2***	***121.4***	***150.7***	***155.0***	***177.0***

Figure 4 can help to explain differences in the productivity recorded over the various test sites.

The generally higher time consumption for SHA3 has already been explained by the need for the operator to become acquainted with the new work conditions. The unusually high “move in” time on the NEV2 site is attributable to increased maneuvering because of height of the trees, scattered large black oak trees and moderately steep terrain. On NEV2, “Other” time is also longer than average, possibly because of a substantial proportion of decisional time – where the operator looked for the best approach to the tree. This is also true for SIE1, where rocky ground required special attention when looking for the best approach to the tree.

It is interesting to notice that “Move out” and “Dump” times are comparatively constant, and do not reach visible peaks even when the terrain was steep or the trees tall. This masks an important observation, namely that under any conditions that may have reduced machine stability the operator would cut the trees and immediately dump them to the ground. Therefore, the effect of these stand conditions would not be evident on the time element analysis. However, the quality of the job performed on difficult sites was definitely inferior to that obtained under more favorable conditions. Notably, because of

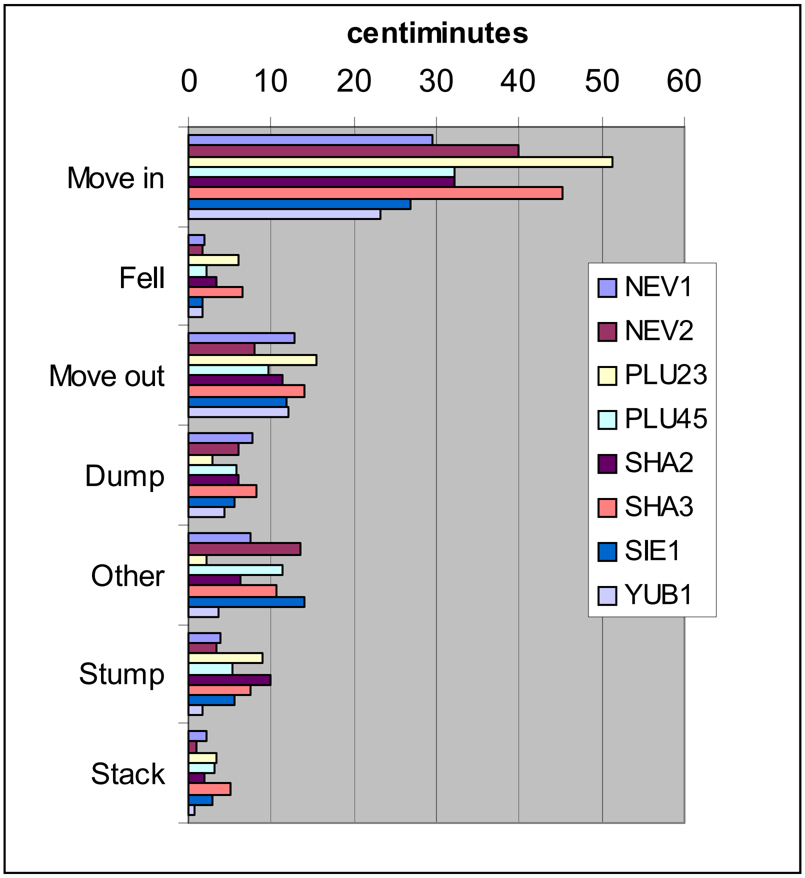


Figure 4 – *Felling: time element consumption by site*

the tall trees and the black oaks, the felling performed at both NEV1 and NEV2 was not very accurate, and several trees were left hanging or criss-crossed. The hanging trees were later pulled down during tree processing. The ASV did an excellent job on such sites as YUB1 and SIE1, that were characterized by moderate slopes and comparatively short trees. It is safe to say that as a feller-buncher the ASV is best suited to trees shorter than 40 feet growing on moderate slopes – at least in selection cuts, where tall trees tend to hang on adjacent leave trees. The ASV feller-buncher performed well in thinning-from-below fuel reduction, but it may be even more efficient in young plantations where trees are small and relatively uniform.

Cycle time data were analyzed statistically to obtain meaningful relationships between element time consumption and significant independent variables. The equations obtained are listed in table 6 and are all significant at the $p < .0001$ level.

Overall, any correlation between productivity and tree size is weak, although often very important. Other unrecorded factors played important roles, especially the positions of cut trees with respect to leave trees or other obstacles. This would have the greatest influence especially on the amount of maneuvering required to reach a tree and move it to the dump site. However, tree size does influence such tasks as felling and dumping. Of course, the thicker the tree stem, the more time it takes to cut through it and the bulkier it is, the more care is required to dump it on a bunch.

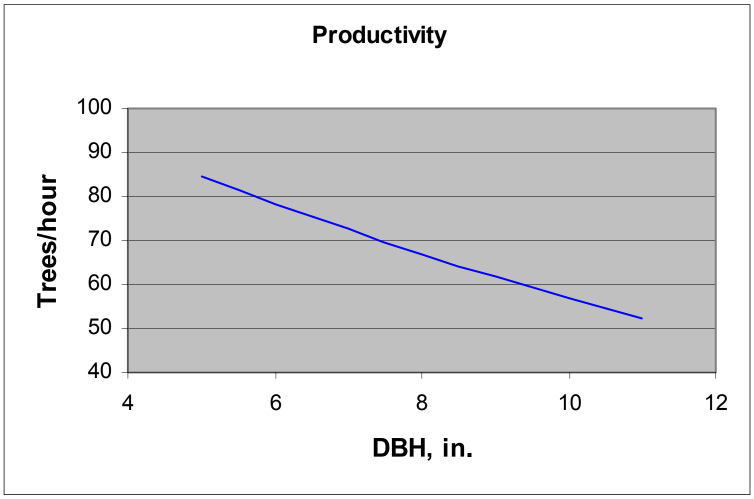
***Table 6** - Prediction models for time consumption: felling (1,262 obs)*

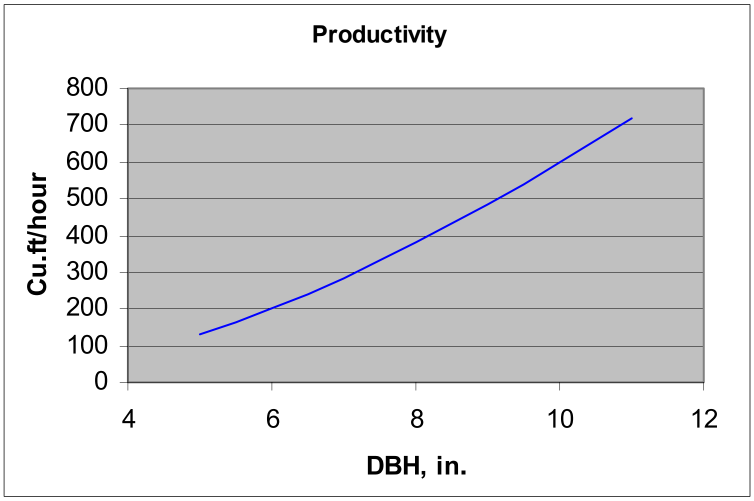
Time Element, cmin/cycle	Regression	r^2
Move to fell	0.10 * Slope % * Tree Volume, cu.ft + 34.94	0.014
Fell	1.18 * DBH, in. – 3.20	0.047
Move to dump	13.14	-
Dump	0.16 * Tree Volume, cu.ft – 0.008 * Removal, cu.ft/ac + 6.45	0.030
Re-cut stump	1.32 * DBH, in. – 1.18	0.013
Stack	2.72	-
Other	1.40 * DBH, in. – 1.71	0.006
Trees/cycle	1	-

The equations shown in table 5 have been used to calculate Net productivity as a function of DBH (Figure 5). The calculations are based on the average DBH-volume relationship obtained for the trees harvested during the study (Appendix B), the average removal (285 cu.ft/ac) and a slope gradient of 15 %. Net productivity can be transformed into Gross productivity by applying a 0.80 factor.

It must be noticed that the head used in the study did not have an accumulator arm and that the ASV could therefore cut only one tree per cycle. The ASV is a very light machine and the operator did not think it was worth to collect more than one 7-in tree inside the head, because the excessive weight would have considerably slowed down maneuvering, canceling the gains of multi-tree handling. However, the ability to accumulate more than one tree per cycle may prove useful when harvesting very small trees: under these conditions the optional accumulator arm should be installed in order to increase productivity.

Figure 5 – *Calculated Net productivity for felling*





Processing

Figure 6 shows processing time element consumption by test site. Site YUB1 is missing because the trees were young (16 years) and their live green limbs reached nearly to the base and were too stout to be cut by the processor. They were instead skidded whole to the landing, where they were later chipped. Again, results for SHA3 should be considered with caution, because this was the very first site and the operator was adjusting his methods. For the rest, the analysis provides interesting insights. The "Move" time is greater on PLU4 and NEV2, which had the steepest slopes. "Process" time appears to be influenced by tree size, and it is greater on the sites where cut trees were larger, such as SHA2, NEV1 and NEV2.

In general, the tree processor performed well. The productivity ranged between 35 and over 50 trees per hour, which is good for a comparatively simple unit. Although it may work best with trees in the 4 to 8 cubic feet range, this machine can treat larger trees without too much trouble, and during the study it actually processed trees up to a maximum size of 20 cu.ft. The most important limitation of the processor is that it only works from left to right and cannot be swung around – thus forcing the ASV to maneuver quite a bit when approaching trees that are on difficult ground.

Once again the data were analyzed statistically to obtain meaningful relationships between element time consumption and significant independent variables. The equations obtained are listed in Table 7 and are all significant at the $p < .0001$ level. They were calculated using all the data, including those from SHA3, since processing seemed to require fewer adjustments than felling and productivity was not substantially lower here than at the other sites.

"Move" and "pick up" take marginally longer for larger trees, but, although significant, the equations that model the activity explain only a very small portion of the total variability. Processing time is strongly correlated to tree size as expressed by merchantable volume and total height. Processing cedar trees seems to require more time than average, and this is also expressed in the model. Tree size also impacts "drop top" time and other time, probably because larger trees have larger tops and other time includes a substantial share of slash piling.

Figure 6 – *Processing: time element consumption by site*

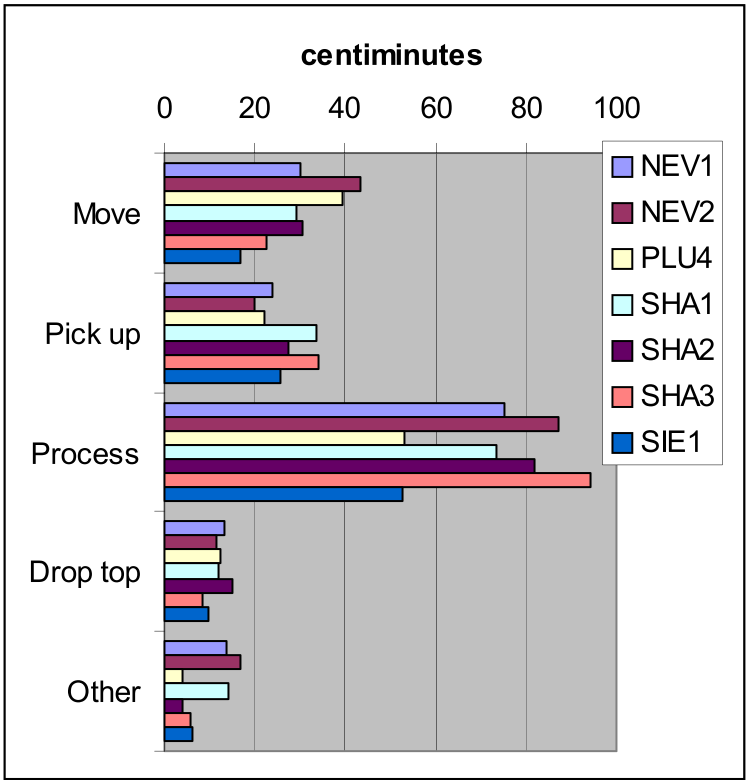


Table 7 - *Prediction models for time consumption: processing (751 obs)*

Time Element, cmin/cycle	Regression	r^2
Move	3.40 * Tree Volume, cu.ft + 16.25	0.066
Pick up	1.24 * Tree Volume, cu.ft + 20.84	0.033
Process	10.08 * Tree Volume, cu.ft + 0.74 * Height, ft + 4.121 * Cedar dummy * Tree Volume, cu.ft + 2.33	0.585
Drop top	0.47 * Tree Volume, cu.ft + 9.97	0.027
Other	2.90 * DBH, in. – 1.54	0.073
Trees/cycle	1	-

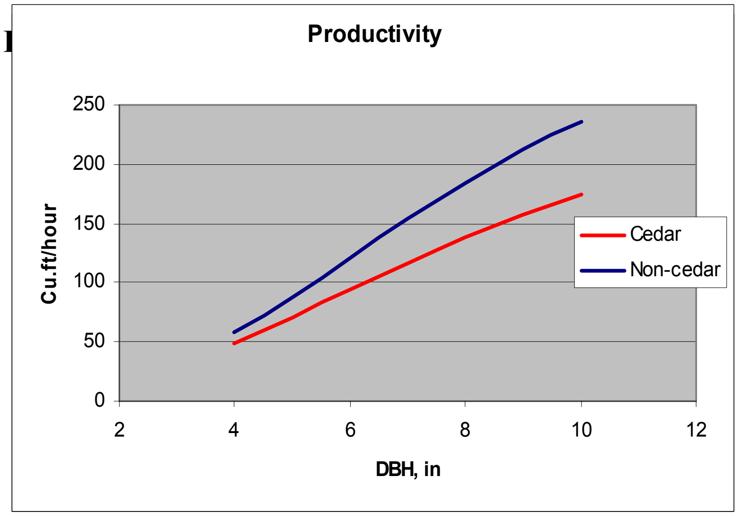


Figure 7 shows the graphs resulting from the application of these models to the average DBH-volume relationship obtained for the trees harvested during the study (see Appendix B). It provides Net productivity figures, which transform into Gross productivity with a 0.80 factor. For a given DBH, cedar trees have a lower volume than non-cedar trees, which explains why more cedar trees are processed per hour for the same DBH. The most significant independent variable in the equations is tree volume, and while it takes longer to process cedar trees than others trees for any given volume, when DBH is used as the independent value, which was done to maintain comparability with the graphs in figure 5, the lower DBH-volume relationship for cedar trees offsets the longer processing time for unit volume.

The number of sawlogs produced from a tree of given volume can be calculated using the equations listed in Appendix D.

<u>Skidding</u>

Skidding was performed under a variety of terrain and operational conditions. Table 8 describes both work conditions and the results obtained. Productivity reported in table 8 is Net productivity, excluding delays. It can be converted into Gross productivity by applying a 0.85 factor, experimentally measured during the study.

Table 8 *– Skidding: work conditions and Net productivity*

Site	Slope, %	Direction	Distance,ft	Sorting	Assortment	Load, cu.ft	Load, pieces	Trips/h	Cu.ft/h
NEV1	14	Uphill	-	-	-	-	-	-	-
NEV2	18	Uphill	647	No	Logs	19.8	13.0	7.6	150.2
PLU2 & 3	12	Downhill	158	No	Trees	16.5	4.9	11.5	189.7
PLU4 & 5	20	Downhill	213	No	Logs	10.9	8.3	16.5	179.8
SHA1	10	Uphill	-	-	-	-	-	-	-
SHA2	2	Level	123	Yes	Logs	13.0	5.6	7.8	101.3
SHA3	2	Level	163	No	Logs	13.4	7.5	19.5	261.1
SIE1	14	Downhill	250	Yes	Logs	14.2	14.2	5.1	74.5
YUB1	10	Downhill	530	No	Trees	29.3	7.5	9.6	282.7
Average, skidding logs						14.8	10.0	12.3	181.5
Average, skidding trees						19.4	5.5	11.1	215.4

The ASV is an excellent skidder, but it does not double well as a shortwood forwarder, especially if sorting is required. If shortwood must be extracted and sorted, it might be better to resort to a different machine. Sorting is especially time consuming for the ASV, since it does not have a boom like loaders have and therefore picking logs from a bunch is quite awkward. That explains the significantly lower productivity observed at SHA2 and SIE1 as compared to the other sites. The impact of sorting on total cycle time is very strong. Figure 8 illustrates this well: because sorting was entered in the “Other” time category, the very long times corresponding to this item at SHA2 and SIE1 give an immediate measure of how much sorting contributes to total time consumption.

That does not mean that the ASV system cannot be used for effective cut to length (CTL) harvesting, but then the work sequence should be modified. Trees should be felled, skidded whole to a landing and processed there. Such a procedure would require sufficient landing space, which may not always be available. Sorting with the ASV should be avoided whenever possible: the machine was not designed for such a job and there are more effective ways to perform it.

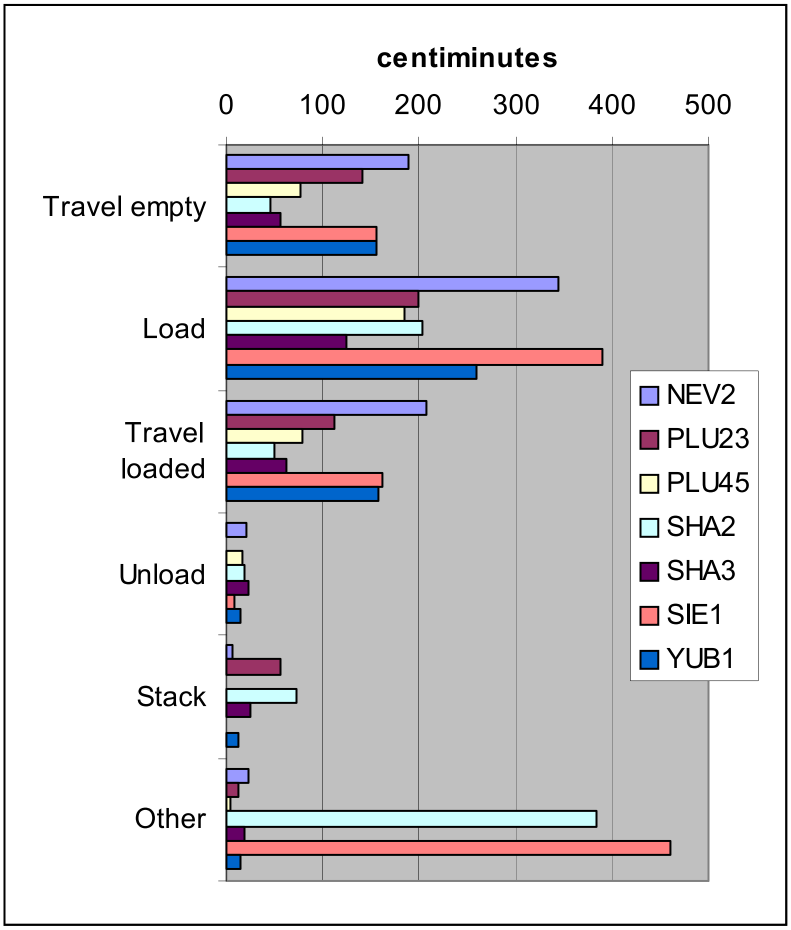


Figure 8 – *Skidding: time element consumption by site*

Skidding data were analyzed statistically in the same manner as the felling and processing data to analyze meaningful relationships between element time consumption and significant independent variables. The equations obtained are listed in table 9 and are all significant at the $p < .0001$ level.

Figure 9 shows the relationship between Net productivity and extraction distance, when extracting downhill on a 15 % slope. For whole tree skidding we assumed an average load size of 20 cu.ft and an average load of 5 trees. For shortwood forwarding the simulated load was 10 logs, for a total volume of 15 cu.ft. These assumptions reflect the average figures recorded throughout the study and shown in Table 8.

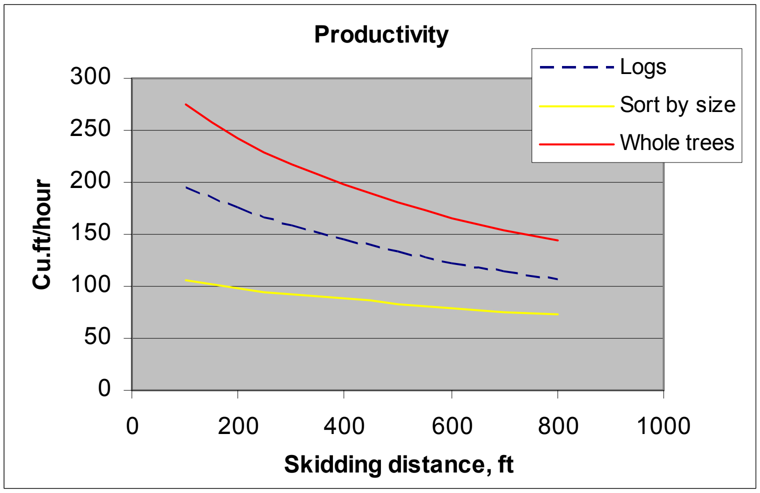
Mastication

In the United States, ASVs are used for mastication more than for any other forestry job. In fact, mastication covered approximately 25 percent of the total work time in our study. The job was conducted under a variety of conditions, especially for terrain roughness and stand density. In most cases, the masticator would cover the site twice: it would do a first pass before felling, in order to remove both the undergrowth and those trees that could not yield at least one small sawlog. Cleaning the understory as a first step was thought to

***Table 9** - Prediction models for time consumption: skidding (230 obs)*

Time Element, cmin/cycle	Regression	r^2
Travel empty	0.17 * Dist, ft + 0.009 * Slope % * Dist, ft – 0.005 * Slope % * Dist, ft * Uphill extraction Dummy + 31.17	0.760
Load	27.62 * Load, pieces – 7.06 * Load, pieces * Log Dummy + 46.35	0.260
Travel loaded	0.191 * Dist, ft + 0.00025 * Slope % * Dist, ft * Load, cu.ft + 55.67	0.566
Unload & stack	If logs = 36.43, if trees = 77.08	-
Sorting logs	If sorting by species = 364.12 If sorting by size = 396.03	-
Other	31.39	-
Load size, cu.ft	6.10 * Tree size, cu.ft – 1.69 * Tree size, cu ft * Log Dummy – 1.78	0.116

Figure 9 – *Calculated Net productivity of skidding*



facilitate all the following operations, especially felling. The second pass was performed as a final treatment before leaving, with the purpose of mulching the limbs and tops left after processing. However, deviations from this general approach were used on SHA1 and SIE1. Pre-harvest mastication was not conducted on SHA1 because the equipment transport trailer broke, making it impossible to safely unload the masticator. At SIE1, the ground was to rocky and the operator feared damage to the masticator and danger to the researchers from flying rock chips. Therefore, it was decided to first fell all the trees, both merchantable and non-merchantable, and move them to comparatively rock-free locations before proceeding with any other operations. In any case, the SIE1 stand was nearly pure pondersosa pine and had minimal undergrowth.

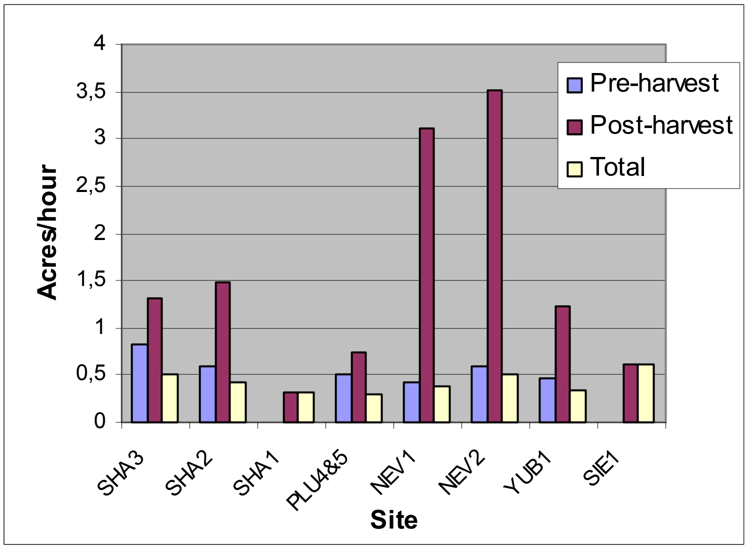
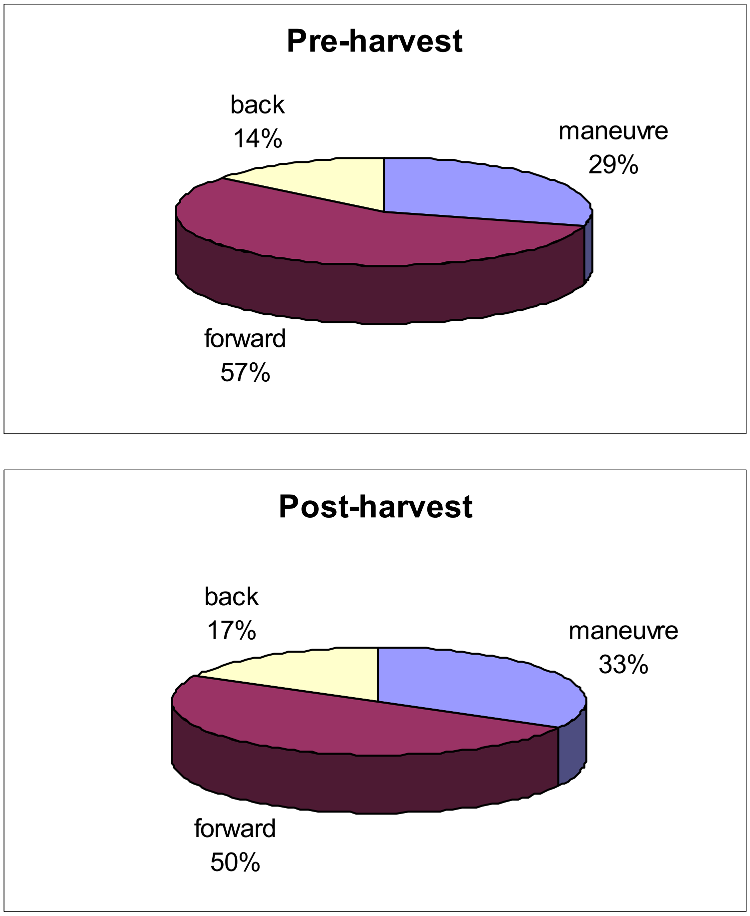


Figure 10 – *Mastication productivity: pre-harvest, post-harvest and total*

Figure 10 shows the productivity observed at the 9 sites. Pre-harvest mastication averaged about 0.5 acres per hour, and there were no huge differences between sites. Post-harvest mastication rates were highly variable, ranging from 0.4 to 3.5 acres per hour. Post-harvest mastication was influenced by harvested tree size, tree species and the intensity of the thinning; these factors impacted the amount of slash produced per unit of area, and therefore the work load for the machine.

Collected data were not suitable for any statistical analysis, essentially because the work was not cyclic. However, timing sessions were conducted on most sites, in order to detect any working patterns. Although the recording forms contained several activity categories, the machine only seemed to run according to three basic modes: masticating while moving forward, masticating while in reverse and maneuvering without masticating. This pattern is described in figure 11, separately for the pre-harvest and the post-harvest passes. The post-harvest pass contained a slightly larger share of maneuvering and of masticating in reverse, which may reflect the need to move between scattered piles of slash, which are also easier to run over. Pre-harvest mastication involves treatment of standing trees, which are often close to each other, hence the lower incidence of maneuvering and of masticating in reverse.

Figure 11 – *Mastication: breaking down Net work time into activities*



Economics

The machine operating costs have been calculated using the Miyata costing method (Miyata 1980) that was specifically developed for forestry equipment cost analysis. The primary assumptions are a depreciation period of 5 years and a service life of 8,000 hours: these are the same cost assumptions used for the ASV by other authors (TheYankeeTreeGroup, 2003).

Two different investment levels were considered, one for the CTL system and another for the whole-tree system. In the first case, the operation will consist of the ASV skidsteer ($45,000), masticator ($9,000) hotsaw ($17,000), processor ($60,000) and grapple ($6,000), for a total investment cost of $137,000. In the second case, the processor is not included so the investment cost drops to $77,000.

A truck and the trailer is required to move the operation between sites. In addition to the harvest equipment costs, the cost of the truck and trailer are required. The investment cost of the transport equipment has been estimated at $40,000. The depreciation of the transport equipment is entirely charged to the operation, because the truck is sitting on site while the ASV is working. On the other hand, its service life has been extended (8 years) and the recovery value slightly increased (30 %) because the truck's engine is used very little. The activity sampling conducted for the present study shows that travel time is only 5 % of the total time, and therefore the truck's engine runs only 80 hours a year! If one adds to that figure 2 hours a day for 200 days a year in order to account for the operator commute to and from the worksite, the total is still limited: 480 hours a year. This corresponds to approximately 20,000 mi/year, i.e. 160,000 mi over the 8 years assumed as the service life of the truck.

Table 10 – *Calculation of equipment operating cost*

Machine description:	ASV CTL	ASV WTS	Truck
1. Input Data:			
Purchase price as of Jan 04 (P, $) =	$137,000	$77,000	$40,000
Machine life (n, years) =	5	5	8
Salvage value, percent of purchase price (sv%)	20%	20%	30%
Utilization rate, ph/sh (ut%) =	70%	70%	20%
Repair and maintenance, percent of depreciation (rm%) =	100%	100%	75%
Interest rate, percent of avg yearly investment (in%) =	4%	4%	4%
Insurance and tax rate, percent of avg yearly investment (it%) =	7%	7%	7%
Fuel consumption (fc, gal/ph) =	1.6	1.2	2.7
Fuel cost per gallon (fcg, $/gal) =	1.4	1.4	1.4
Lube and oil, percent of fuel cost (lo%) =	37%	37%	37%
Scheduled machine hours (SMH, sh/year) =	1600	1600	1600
2. Calculations:			
Salvage value (S, $) = (P*sv%) =	27400	15400	12000
Annual depreciation (AD, $/year) = [(P-S)/n] =	21920	12320	3500
Average yearly investment (AYI, $) = [(((P-S)*(n+1))/2n)+S] =	93160	52360	27750
Productive Machine Hours (PMH, ph/year) = (SMH*ut%) =	1120	1120	24
3. Ownership costs:			
Interest cost (IN, $/year) = (in%*AYI) =	3726	2094	1110
Insurance and tax cost (IT, $/year) = (it%*AYI) =	6521	3665	1943
Yearly ownership cost (F$, $/year) = (AD+IN+IT) =	32168	18080	6553
Ownership cost per SMH ($/sh) = (F$/SMH) =	**20.10**	**11.30**	**4.10**
Ownership cost per PMH ($/ph) = (F$/PMH) =	28.72	16.14	274.57
4. Operating costs:			
Fuel cost (F, $/ph) = (hp*fcr*fcg) =	2.3	1.7	3.8
Lube cost (L, $/ph) = (F*lo%) =	0.85	0.64	1.42
Repair and maintenance cost (RM, $/ph) = (AD*rm%/PMH) =	19.57	11.00	8.20
Operating cost per PMH (V$/PMH) = [F+L+RM+(WB/ut%)] =	22.73	13.37	13.46
Operating cost per SMH (V$/SMH) = (V$/PMH*ut%) =	**15.91**	**9.36**	**2.69**
5. Total Machine Costs			
Total cost per SMH ($/SMH = (F$/SMH+V$/SMH)	**36.01**	**20.66**	**5.80**

The cost calculation is reported in table 10. Assuming an operator wage of $25 per hour, the costs will be $67.80 and $52.44 respectively for the CTL and the whole-tree operation, truck included.

The calculation reported here is just an example. Interested parties can calculate the operating cost of their machinery, under their specific assumptions using the model developed as a result of this project.

The costs estimated above do not include administration costs, management cost and profit.

Modeling

The significant mathematical relationships obtained from this study and reported above were used to generate a calculation model capable of predicting time consumption as a function of site characteristics and moving distance.

The model calculates felling, processing and skidding cycle time using the equations shown in tables 6, 7 and 9. Cycle time is then transformed into actual work time by applying the respective coefficients, namely: 0.80, 0.80 and 0.85. For mastication, the average area production rate (0.4 acres per hour) is applied throughout the range of options. The four productive tasks are then summed up into Productive work time, and the accessory times are added as a percentage of this last figure, as calculated from the study data (table 11). Miscellaneous activities include changing implements.

Moving time was calculated using the following function:

1.20 hours for loading + move distance, mi. / 31 mph + 1 hours for unloading

The model allows for simulating different operational procedures. In particular, users can check the effect of fitting their trucks with a small workshop: if they choose this option the model does not include in the calculation the “Go to shop” accessory time.

Table 11 – *Accessory times as a percentage of Productive work time*

Activity	%
Reconnaissance	3.7
Repair & Maintenance	13.7
Go to shop	13.2
Miscellaneous	15.1

The model was validated by comparing the predicted time consumption and the actual time consumption for the 9 test sites. The results are reported in Table 12, which demonstrates the capacity of the model to calculate accurate time consumption figures. Appendix E contains a detailed site-by-site comparison.

Table 12 – *Model validation*

Task	Calculated	Actual	% error
Mastication	53.8	54.8	-1.9
Felling	33.6	37.7	-11.0
Processing	41.5	40.9	1.4
Skidding	61.1	62.7	-2.6
Reconnaissance	6.9	7.2	-3.2
Repair and maintenance	51.1	52.8	-3.2
Miscellaneous	28.6	29.3	-2.3
Total time	**276.6**	**285.4**	**-3.1**

Finally, the time calculation worksheet, has been integrated with the costing model, so that all can be translated into the necessary dollar figures. The model therefore provides a useful tool to ASV operators when costing a job or checking the profitability of a contract. Similarly, prospective users can better evaluate the suitability of the system to their own needs.

Based on the model, figure 12 shows that the ASV system is not very sensitive to parcel size, and can operate on very small parcels without a substantial increase in operational cost. The harvesting system has more impact on treatment cost, which is much lower when harvesting whole trees than sawlogs.

Figure 13 shows the variation of sawlog production cost as a function of tree size and removal intensity. The table helps attributing a value to the products that can be obtained from the treatment. The difference between this value and the market price is the cost of the treatment on a unit product base: owners can decide if the treatment is worth the additional cost. What is more important is that the table shows the variation of this cost with harvesting conditions, enabling owners to manipulate these conditions in order to meet the cost that they are ready to pay.

Figure 12 – *Treatment cost as a function of parcel size*

Figure 13 – *Unit cost of sawlogs as a function of tree size and removal intensity*

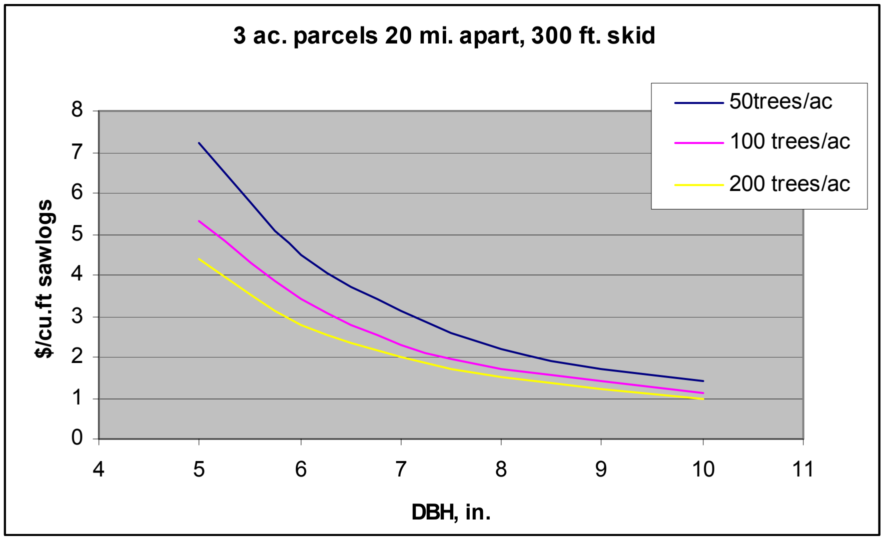
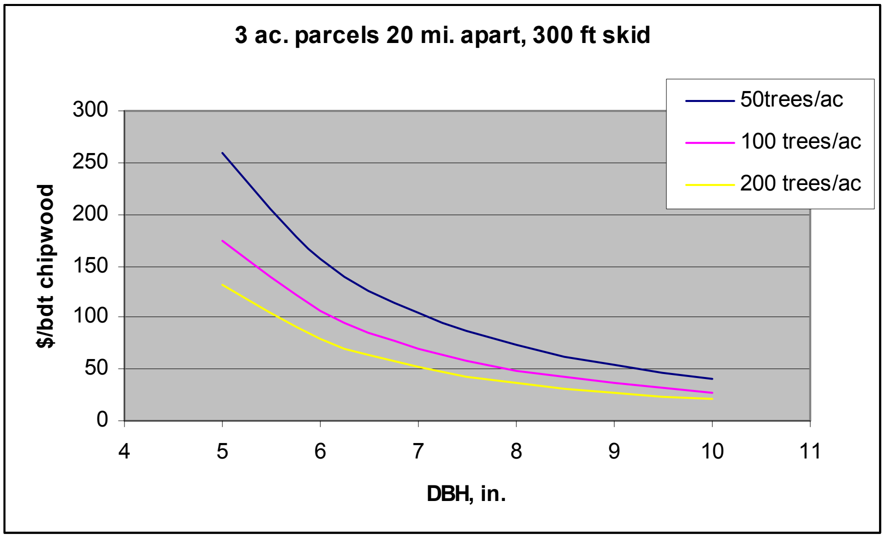


Figure 14 reports exactly the same data for whole-tree harvesting. There are endless ways to use the model and those reported here are just a few examples. Interested parties can download the model from the UC Extension Service Homepage at: http://ucce.ucdavis.edu/fuelreduction/.

Figure 14 – *Unit cost of chip wood as a function of tree size and removal intensity*



Conclusions

The ASV system is a self-contained operation that is very mobile and capable of working in dense forest conditions. It was also found to be a system that is very well-suited to small-parcel conditions around home sites.

The study fully confirmed these hypotheses, as the operation moved very quickly from site to site, using narrow roads and small landings in several instances.

Although the machine performed reasonably well in all sites, productivity is highest only under certain conditions. The ASV performed best on even terrain, moderate slopes and softwood trees with a DBH between 5 and 8 inches. Productivity will be less on slopes greater than 25 percent, if the soil is wet or snow-covered, or if the trees are larger than 10 inches DBH.

Under good terrain conditions and with trees measuring 7 inches DBH, productivity will reach 60 trees/SMH for felling, and 27 trees/SMH for processing – corresponding to 235 cu.ft/SMH and 105 cu.ft/SMH respectively. Under the same conditions and on a 400 ft. skid, the productivity of skidding can be estimated to 115 cu.ft/SMH and 165 cu.ft/SMH respectively for logs and whole trees. Mastication proceeds at a rate of approximately 0.4 acres/SMH.

Several mechanical problems were experienced during the course of the tests: approximately 15 % of the total worksite time was spent on repairs or waiting for repairs to be done. This situation can be significantly improved by carrying a more complete set of necessary spares and tools, which were not always available during the trial. If they had been, repair time would have dropped to 6 % of total worksite time, a figure that one can regard as acceptable. Like any mechanized loggers, ASV owners should load their trucks with spares, a vice, a welder and possibly a small hoist.

If applied to the right job the ASV is an excellent machine. In particular, it has a great potential as a feller-buncher. The disc saw manufactured by Davco, uses the same technology of the large Canadian models, but weighs 1,200 pounds instead of 6,000. The price is also modest at $17,000 – a small fraction of what one will pay for a standard model. The compact shape of the machine guarantees excellent stability even when holding the cut tree upright and maneuvering with it.

Davco also manufactures the processor head used during the study. Compared to European models, the Davco head is definitely simpler. It has only one feed-track, matched by a large idler wheel that pushes the tree against the track. In addition log diameter measurement is offered as an option and not as standard. Overall, the machine is below European standards. Davco quotes $ 60,000, which is a bit steep for a machine that simple. The reason for that is mainly the limited number of units produced: Davco says that the price may drop to around $45,000, if production grows. In any case, the machine is definitely sturdy, and today there are only two heads that can be used with an ASV: Davco's and Hahn's. Besides, this processor has some interesting characteristics, like the active joint that connects it to the front lift and allows one to keep cut trees upright inside the head, similar to a feller-buncher. This is very helpful in thinning; when there is little space to lay the cut tree, one can cut it and then move it to an opening before laying it horizontal for processing. This is impossible with European-style dangle heads, which may direct the tree fall but cannot hold the tree upright. For this same reason, the ASV may be better suited as a tree harvester than as a log processor used for delimbing and bucking pre-felled trees. Handling pre-felled trees is easier if one has a boom, while the ASV carries all its attachments on a front lift rather than a boom.

The ASV is an excellent skidder, but it does not double well as a shortwood forwarder, especially if sorting is required. Sorting is especially time consuming for the ASV, since the machine does not have a boom such as those on forwarders and loaders: therefore picking logs from a bunch is quite awkward.

That does not mean that the ASV system cannot be used for effective cut to length harvesting, but then the work sequence should be modified – and this might be one of the most important teachings obtained from the study. It may be more efficient to fell the trees and skid them whole to a landing where they are processed. Of course, such procedure would require sufficient landing space, which may not always be available, especially on small-parcel conditions. The ASV can be used for sorting but it should be avoided whenever possible: the machine was not designed for such job and there are more effective ways to perform it.

Although it can certainly be perfected, the ASV system is a good, low-investment tool for small-tree, small-parcel operations. This study suggests directions to make the ASV's use more effective, and the situation may further improve if the new ASV version is really better, simpler and more reliable, as the manufacturer claims.

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Appendix A – Time Element Description

APPENDIX A - TABLE 1. — Description of time elements: felling

Time element	Description
Move in	The machine moves in the stand, approaching the tree to be cut. It includes locating the tree and deciding what path to follow for reaching it. It starts after the machine has dumped the previous tree and ends when the saw start cutting into the next tree.
Fell	The saw cuts through the tree. It ends when the tree is free from the stump
Move out	The machine moves the tree to the dump site. It ends when the tree is dropped to the ground. The stopwatch button is pushed when the stem forms 45° with the horizontal.
Dump	The tree falls on the ground or on the other trees laying on the ground if a bunch is being formed. It ends when the tree is horizontal.
Stump	The operator cuts projecting stumps in order to makes his travel smoother or to approach another tree. It includes maneuvering to address the stump from an appropriate angle.
Stack	Pushing the butt of the felled tree with one of the hotsaw skids in order to move the tree aside or to adjust its butt with those of the other trees in the bunch formed on the ground.
Other	Any other productive time, e.g., clearing of obstacles, piling of slash, etc.

APPENDIX A - TABLE 2. — Description of time elements: tree processing

Time element	Description
Move	The machine approaches the tree to be processed. It starts after the machine has dumped the top of the previous tree and ends when the head comes into contact with the next designated tree.
Pick-up	The knives slip under the tree, grab it and lift it free from the ground or the other trees. The head is moved so that the stem lodges between the arms and on the feed track. The upper roller is pushed against the tree. It ends when the saw emerges from its casing in order to trim the tree butt.
Process	The tree is fed through the knives, delimbed and bucked. It ends when the last log (sawlog or firewood log) is bucked and falls to the ground.
Drop top	The undelimbed tree top is dropped to the ground, generally away from the log pile. It includes the short maneuver to clear the log pile.
Other	Any other productive time, e.g., clearing of obstacles, piling of slash, or stacking logs, etc.

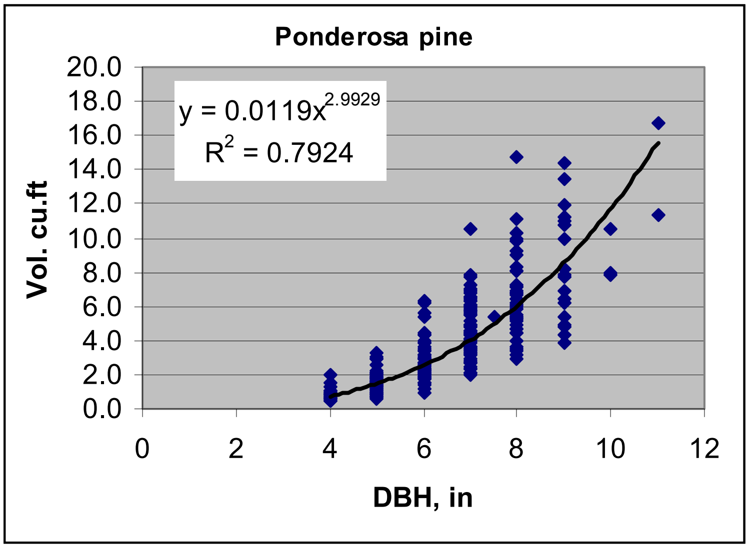
APPENDIX A - TABLE 3. — Description of time elements: skidding

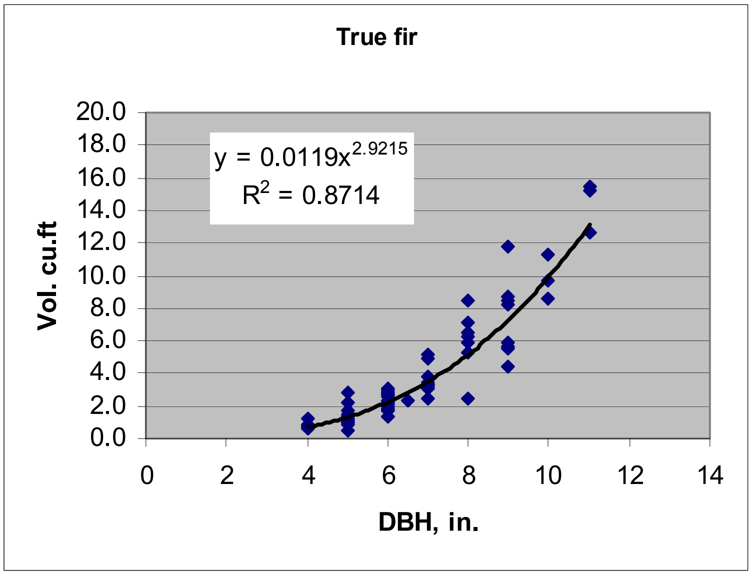
Time element	Description
Travel empty	The machine moves from the landing to the load site. It ends when the machine stops and begins maneuvering to approach the logs to be picked up.
Load	Formation of a load. It may include several short trips to an intermediate accumulation site where logs from smaller piles are gathered. It ends when the machine picks up a whole load and leaves for the landing.
Travel loaded	The machine moves to the landing with a full load. It ends when the machine reaches the landing and moves to the log pile where it will drop its load.
Unload	The logs are placed on the log pile or dropped to the ground. It ends when the log grapple is open and free of the logs
Stack	The logs are picked up again and rearranged on the pile, in order to form regular stacks.
Other	Any other productive time, e.g., clearing of obstacles, piling of slash, locating the best path, etc.

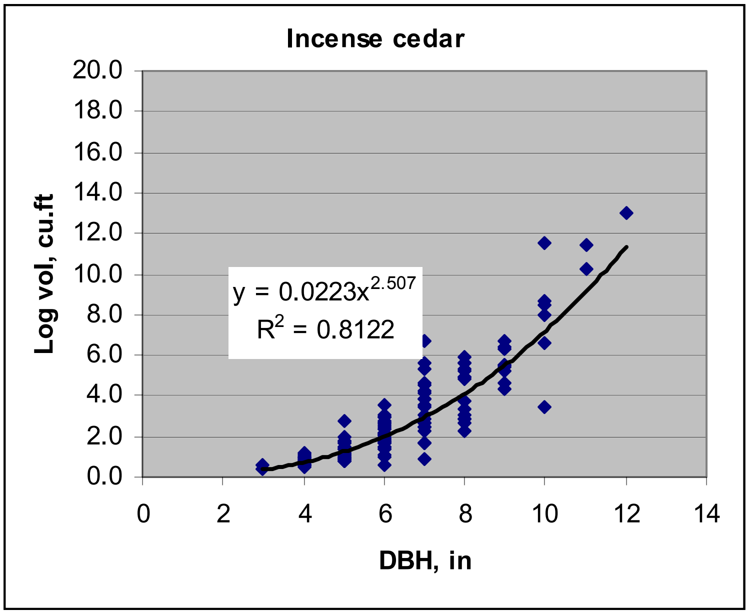
APPENDIX A - TABLE 4. — Description of time elements: masticating

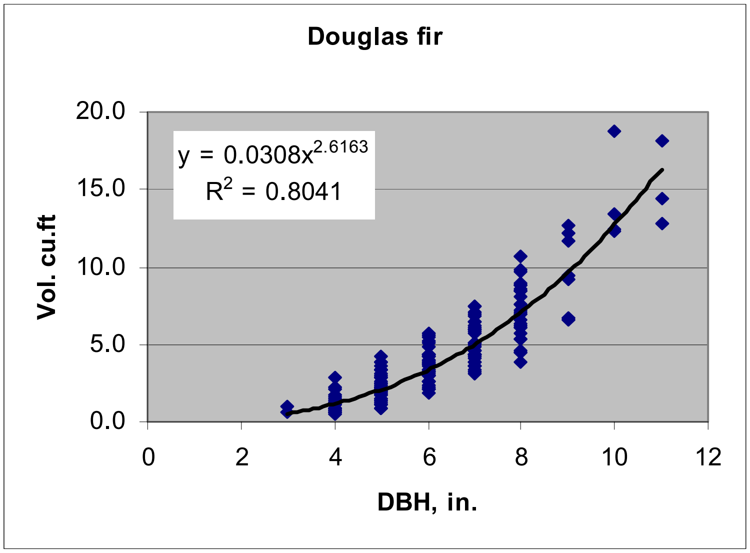
Time element	Description
Forward	The machine moves forward, with the masticator flailing the vegetation in front of it or on the ground.
Reverse	The machine moves in reverse, with the masticator flailing the vegetation pushed on the ground while moving forward.
Maneuver	The machine maneuvers to attack the vegetation from the right angle.
Other	Any other productive time

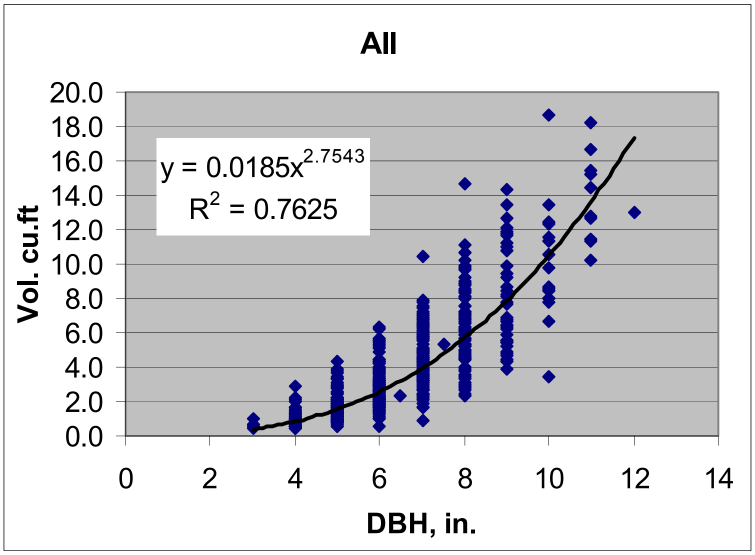
Appendix B – Volume tables calculated from the study (sawlog volume as a function of Diameter at Breast Height)



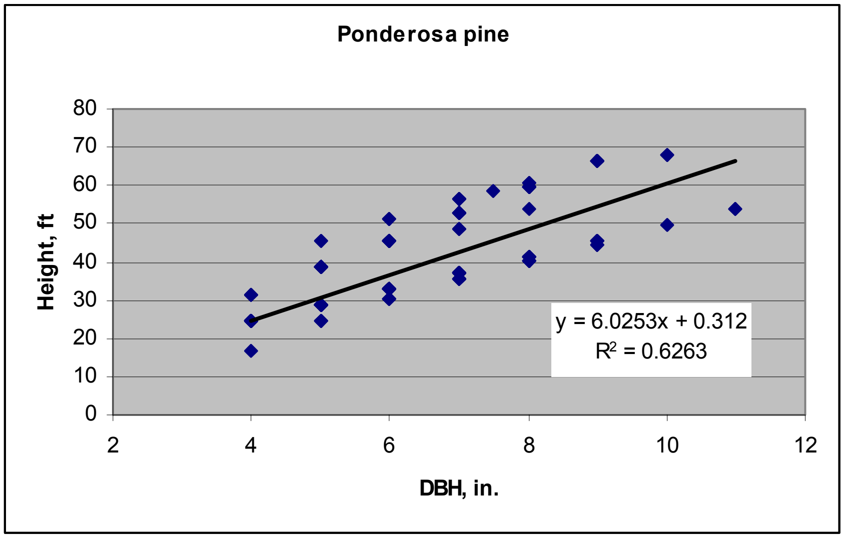


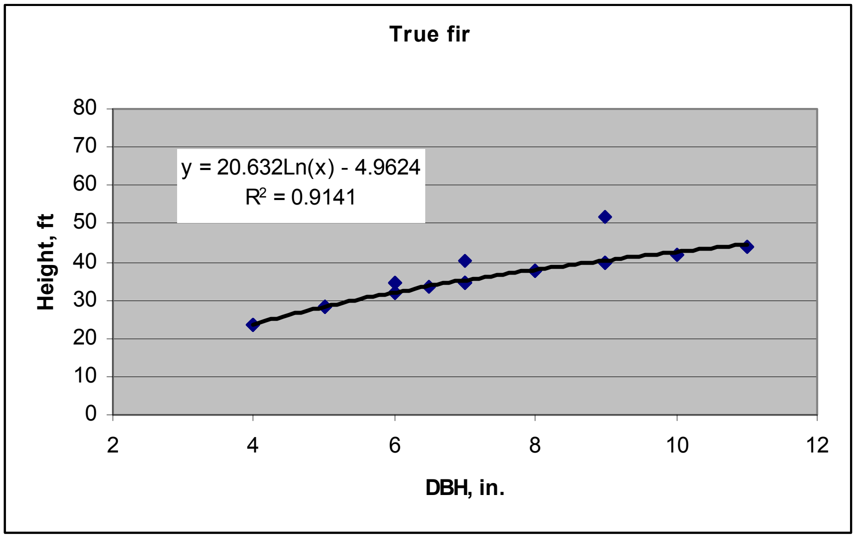

Incense cedar
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Log vol, cu.ft
0
2
4
6
8
10
12
14
DBH, in
y = 0.0223x^2.507
R^2 = 0.8122

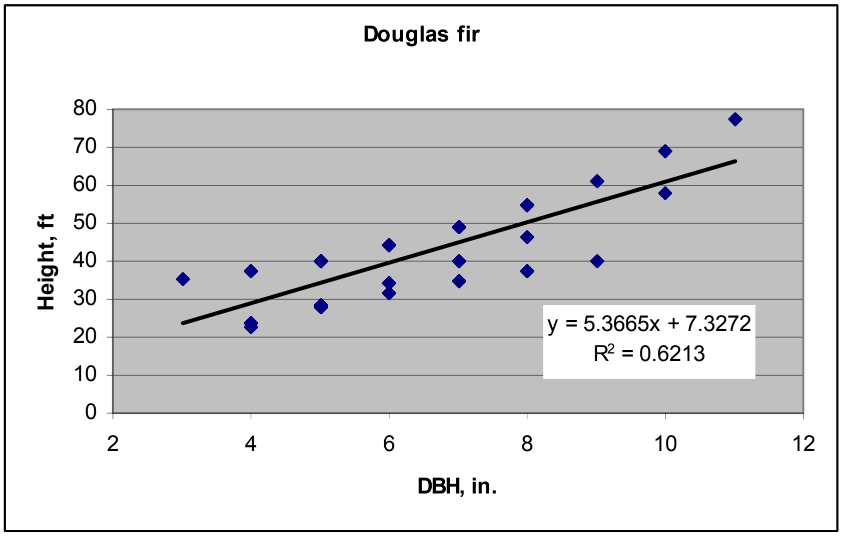

Douglas fir
20.0
15.0
10.0
5.0
0.0
Vol. cu.ft
0
2
4
6
8
10
12
DBH, in.
y = 0.0308x^2.6163
R^2 = 0.8041

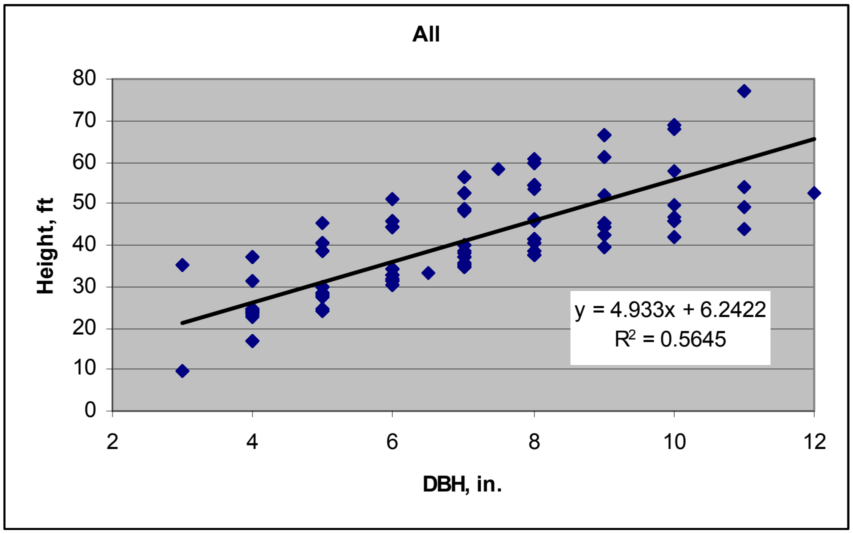

All
y = 0.0185x^2.7543
R^2 = 0.7625
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Vol. cu.ft
0
2
4
6
8
10
12
14
DBH, in.

Appendix C – DBH-Height charts (total tree height as a function of DBH): values from all sites






Douglas fir
Height, ft
DBH, in.
0
10
20
30
40
50
60
70
80
2
4
6
8
10
12
y = 5.3665x + 7.3272
R² = 0.6213


All
Height, ft
DBH, in.
0
10
20
30
40
50
60
70
80
2
4
6
8
10
12
y = 4.933x + 6.2422
R² = 0.5645

APPENDIX D - TABLE 1. — Number of sawlogs obtained from a tree of given volume

Logs per tree, #	Regression	r^2
Ponderosa pine	0.367 * Tree volume, cu.ft + 1.444	0.695
Incense cedar	0.252 * Tree volume, cu.ft + 1.151	0.430
Douglas fir	0.207 * Tree volume, cu.ft + 1.515	0.491
White fir	0.146 * Tree volume, cu.ft + 1.280	0.398
All together	0.274 * Tree volume, cu.ft + 1.411	0.506

Appendix E – Comparison between predicted and actual time consumption figures

Site		NEV1		NEV2		PLU23		PLU45		SHA1	
Task		Est'd.	Actual	Est'd.	Actual	Est'd.	Actual	Est'd.	Actual	Est'd.	Actual
Mastication	hours	9.5	10.2	8.5	6.7	0.0	0.0	10.8	13.4	2.3	3.7
Felling	hours	2.9	2.9	1.7	1.3	10.8	14.9	4.5	4.6	2.0	2.5
Processing	hours	6.7	6.2	3.8	3.8	0.0	0.0	8.8	7.8	4.7	4.9
Skidding	hours	4.8	3.8	4.2	3.7	12.8	20.2	7.2	10.5	3.6	3.7
Reconnaissance	hours	0.9	1.4	0.7	0.7	0.9	1.2	1.1	0.4	0.5	0.0
Repair and maintenance	hours	6.4	15.1	4.9	2.0	6.4	1.3	8.4	7.0	3.4	12.1
Miscellaneous	hours	3.6	4.3	2.7	1.0	3.6	1.6	4.7	5.7	1.9	11.0
Total time		34.7	43.9	26.6	19.2	34.4	39.2	45.5	49.4	18.2	38.0
Error of our estimate, %		-21.1		38.3		-12.0		-7.8		-52.2	

Site		SHA2		SHA3		SIE1		YUB1	
Task		Est'd.	Actual	Est'd.	Actual	Est'd.	Actual	Est'd.	Actual
Mastication	hours	5.0	4.7	6.5	5.1	4.5	3.0	6.8	8.0
Felling	hours	2.1	2.6	1.8	2.3	4.8	4.8	3.0	1.8
Processing	hours	4.9	5.0	3.7	4.9	9.0	8.4	0.0	0.0
Skidding	hours	5.8	4.4	2.7	2.5	15.5	10.5	4.7	3.3
Reconnaissance	hours	0.6	0.0	0.5	0.0	1.2	2.9	0.5	0.6
Repair and maintenance	hours	4.8	0.4	3.9	1.4	9.1	11.5	3.9	2.0
Miscellaneous	hours	2.7	2.2	2.2	1.0	5.1	1.7	2.2	0.8
Total time		25.8	19.3	21.3	17.3	49.1	42.8	21.1	16.4
Error of our estimate, %		33.7		23.1		14.8		28.3	