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COSTS OF HARVESTING FOREST BIOMASS ON STEEP SLOPES WITH A SMALL CABLE YARDER: RESULTS FROM FIELD TRIALS AND SIMULATIONS

John E. Baumgras and Chris B. LeDoux

USDA Forest Service
Northeastern Forest Experiment Station
Morgantown, West Virginia 26505

ABSTRACT

Cable yarding can reduce the environmental impact of timber harvesting on steep slopes by increasing road spacing and reducing soil disturbance. To determine the cost of harvesting forest biomass with a small cable yarder, a 13.4 kW (18 hp) skyline yarder was tested on two southern Appalachian sites. At both sites, fuelwood was harvested from the boles of hardwood trees 10 to 36 cm (4 to 14 inches) in dbh. The volume of pieces yarded ranged from 0.01 to 0.63 m^3 (0.2 to 22.4 ft^3). With a crew of four on a small clearcut block and piece volumes averaging 0.14 m^3 (5.1 ft^3), yarding costs were \$12.03 per m^3 (\$33.70 per cunit). With a crew of two on a site previously harvested for sawlogs, it cost \$6.78 per m^3 (\$19.00 per cunit) to yard pieces averaging 0.21 m^3 (7.5 ft^3). Because productivity was generally constrained by the yarder's 429 kg (1,150 lb) mainline pull capacity, the two-person crew proved the most efficient. Production and cost analyses integrating field studies with computer simulation showed that the total cost of yarding biomass with a two-person crew could range from \$5.50 to \$11.00 per m^3 (\$15.00 to \$31.00 per cunit), depending upon average piece volume. This analysis also revealed a tradeoff between biomass utilization and total yarding cost: costs can be reduced by limiting the minimum piece volume yarded.

Keywords. Timber harvesting, cable yarding, biomass, logging cost, simulation.

INTRODUCTION

The large cable yarders that were once used on Appalachia's steep slopes disappeared along with the old-growth timber, but interest in cable yarding has been renewed by the concern over the environmental impact of harvesting timber on steep slopes with conventional ground-based systems. A study conducted in north-central West Virginia found that 1 km of skidroad was required to harvest 5 ha of steep ground with rubber-tired skidders (20 acres $mile^{-1}$ of road), whereas 20 ha per km of road could be harvested by a skyline yarder (80 acres $mile^{-1}$ of road).[1] Increased road spacing resulting from the use of cable yarder systems improves the aesthetic quality of harvest areas and significantly reduces the potential for soil erosion. Cable yarding also reduces ground disturbance on nonroad portions of harvest areas.[2]

Because of the high cost, expensive rigging, and long setup time of medium- and large-capacity cable yarders, their use in the eastern mountains has been limited to removals of high-value sawlogs or high-volume biomass.[3] In this region, there are also numerous opportunities for low-volume biomass harvests on steep slopes. These include regeneration cuttings on poor sites, thinnings on better sites, and recovery of harvesting residue.

Economic yarding of low-volume removals on steep slopes may require low-cost, highly mobile yarders such as the Bitterroot Miniyarder (Figure 1). Developed by the USDA Forest Service's Missoula Equipment Development Center, this 13.4 kW (18 hp) yarder can be mounted on a small truck or trailer and operated by forest crews.[4] Reports by Brown and Bergvall,[5] and Cubbage,[6] indicate that this yarder has potential for harvesting small trees on steep slopes. This paper presents results of field and simulation studies of harvesting forest biomass with the Bitterroot Miniyarder.

YARDING SYSTEM

The yarder studied was rigged as a live skyline, as shown in Figure 2. The skyline could be slackened or tightened as required during yarding. Yarding was done uphill, and the carriage returned by gravity when the mainline was slackened. When the carriage engaged the moveable stop, it clamped onto the skyline and released the mainline that fed through the carriage. The logs were attached to the mainline with wire-rope chokers. When the mainline drum was engaged and the end of the mainline reached the

Figure 1. The bitterroot miniyarder

carriage, the skyline clamp released. The carriage and logs then returned to the landing. The lift provided by the skyline was generally sufficient to keep the front of the logs off the ground during yarding.

YARDING STUDIES

The Bitterroot Miniyarder was studied on two steep sites in the southern Appalachians to determine its yarding cost and evaluate the effects of crew size and site conditions on yarding cost. Time and motion studies were conducted to measure and record its performance. All volume measurements and weight estimates included both wood and bark.

The field sites evaluated had slopes ranging from 20 to 45 percent. On both sites, bolewood was harvested from trees 10 to 36 cm (4 to 14 inches) dbh and utilized for fuelwood. Much of this material could also have been utilized for roundwood pulpwood or small diameter logs for low-quality sawn products. Before yarding, all trees were limbed and topped with chainsaws. Although harvesting limbwood and topwood would have significantly increased biomass yields, the small yarder could not deliver enough wood to justify a costly whole-tree chipper.

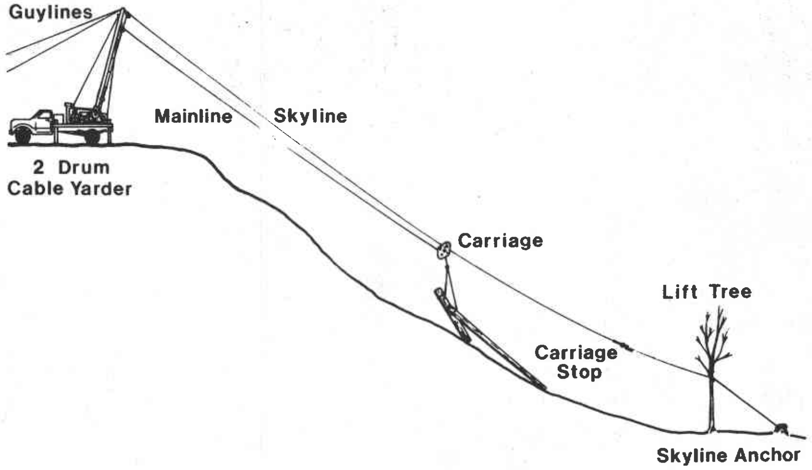

Figure 2. Cable yarder rigged as live skyline

The 429 kg (1,150 lb) mainline pull capacity of the small yarder[7] limited turn volumes on both sites to 0.68 m^3 (24 ft^3). Therefore, trees larger than 25 cm (10 inches) in dbh were bucked to keep bole sections within the yarder's capacity.

Site 1 was a 0.81 ha (2.0 acre) fuelwood clearcut that yielded 94 m^3 per ha (1,350 ft^3 $acre^{-1}$). This fan-shaped unit was yarded to a single landing, using four skyline corridors. Yarding was done with a crew of four: a yarder operator, one person unhooking logs at the landing, and two chokersetters. A small crawler tractor was used to clear the landing and deck the fuelwood. Trees harvested from this hardwood site were predominantly oaks and hickories, averaging 19.6 cm (7.7 inches) in dbh.

On Site 2, two 0.61 ha (1.5 acre) units yielded 77 m^3 per ha (1,100 ft^3 $acre^{-1}$). On each of these rectangular units, one corridor was used with a crew of two, one operating the yarder and unhooking, the other hooking chokers. All wood was decked under the skyline, so no tractor was needed to swing logs away from the yarder. Sawlogs had previously been harvested from this site, and all residual trees had been felled to promote the regeneration of desirable tree species. Residual trees harvested averaged 19.1 cm (7.5 inches) in dbh. The predominant tree species were oak, hickory, and yellow-poplar. Bolewood residue from sawtimber trees was harvested together with the bolewood from residual trees felled during site preparation.

The yarding conditions and yarding cycle characteristics from both sites are summarized below:

Yarding Conditions	Site 1		Site 2	
	Mean	Range	Mean	Range
Piece weight - kg	136	5-653	187	15-537
- lb	300	12-1439	412	32-1183
Piece volume - m^3	0.14	0.01-0.63	0.21	0.01-0.62
- ft^3	5.1	0.2-22.4	7.5	0.5-22.0
Slope yarding distance - m	63	8-107	87	14-165
- ft	208	25-350	285	45-540
Yarder Cycle Characteristics				
Productive time - min	4.25	1.7-7.6	3.78	1.6-9.5
Delay time - min	0.95	0-8.3	1.09	0-11.8
Pieces yarded	2.3	1-5	1.5	1-5
Volume yarded - m^3	0.3	0.08-0.67	0.3	0.03-0.67
- ft^3	11.6	2.7-24.0	11.1	1.0-24.0
Weight yarded - kg	308	82-635	280	23-518
- lb	680	180-1400	618	50-1143

COST AND SIMULATION ANALYSIS

Based upon 1983 equipment costs, the estimated daily cost of the yarding operation was $270.00 per 8-hour day with a four-person crew, or $166.00 for a crew of two.[7] The cost estimates assume wage rates of $5.00 per hour plus 30 percent payroll costs; and include fixed and operating costs for the yarder, two chainsaws, and a radio for communication between the yarder operator and the chokesetters. The total stump-to-landing yarding cost at site 1 was $12.03 per m^3 ($33.70 $cunit^{-1}$); at site 2 it was $6.78 per m^3 ($19.00 $cunit^{-1}$). These costs estimates are based on the production rates sampled at each site, and include the cost of moving the yarder and changing yarding corridors. The unit cost on site 1 does not include the tractor and operator used to move yarded wood from the yarder deck.

The difference in yarding costs between sites 1 and 2 can be attributed to both crew size and yarding conditions. To compare crews under equal yarding conditions, THIN--a cable yarder simulation model[8,9] --was used with the yarder cycle-time regression equations developed from the time-study data.[10] The simulation results showed that under similar operating conditions, productivity is constrained by the capacity of the small yarder. Consequently, the cost of additional crew members could not be offset by increased production, and for most applications, the two-person crew would be most efficient.

Computer simulation was also used to explore the effects of site factors such as average piece volume and slope yarding distance on production and cost. These results showed average piece volume to be the most important variable affecting yarding cost. The analysis of piece volume effects assumed a crew of two, a yarding corridor 168 m (550 ft) long by 37 m (120 ft) wide, and a volume hrvested of 84 m per ha (1,200 ft^3 $acre^{-1}$). When average piece volume was increased from 0.05 to 0.40 m^3 (2 to 14 ft^3), yarding costs declined from \$11.00 per m^3 (\$30.80 $cunit^{-1}$), to \$5.50 per m^3 (\$15.40 $cunit^{-1}$) (Figure 3). Figure 3 was developed to show the general nature of the relationship between average piece size and total yarding cost when volume per acre is held constant. These results agree with practical experience, which shows that bigger pieces are cheaper to yard.

For a specific harvest unit, the effect of piece size can be exploited by designating a minimum piece size. Although this will reduce total yarding cost, it will also reduce the amount of biomass harvested. To demonstrate this, the yarding of unit 2 was simulated using successively larger minimum piece volume limits. The results in table 1 show that as the minimum piece volume was increased from 0.01 to 0.28 m^3 (0.5 to 10.0 ft^3), the portion of available bolewood that was harvested declined to 46.8 percent. Yarding costs also declined from \$6.82 per m^3 (\$19.09 $cunit^{-1}$), to \$6.11 per m^3 (\$17.10 $cunit^{-1}$). The cost was minimal with a piece-volume limit of 0.14 m^3 (5.0 ft^3), which utilized 85 percent of the available bolewood. Although the landowner's objectives may preclude the use of piece-size limits, it is important to recognize its value in harvesting small pieces of biomass.

An alternative approach to minimizing residue yarding cost proposed by LeDoux,[11] is to establish piece-size limits by yarding distance zones. This approach permits increased utilization close to the yarder, but imposes

Table 1. Simulation results illustrating the effect of minimum piece volume limits on total yarding cost for the Bitterrtoot Miniyarder and percent of bolewood biomass utilized on unit 2

Minimum Piece volume[a/]		Bolewood volume harvested	Total yarding cost	
m^3	cubic feet	percent	dollars/m^3	dollars/cunit
0.01	0.5	100.0	6.82	19.09
0.05	2.0	97.3	6.43	18.01
0.08	3.0	94.8	6.22	17.43
0.11	4.0	90.3	6.42	17.97
0.14	5.0	85.6	6.08	17.02
0.17	6.0	79.2	6.27	17.56
0.20	7.0	72.6	6.12	17.13
0.22	8.0	64.6	6.18	17.29
0.25	9.0	57.0	6.14	17.19
0.28	10.0	46.8	6.11	17.10

[a/] Volume of smallest piece yarded, not average piece volume.

successively larger piece-size limits as yarding distance increases. The tradeoff of piece volume and slope distance helps reduce the effects of slope yarding distance on yarding cost.

The effect of slope yarding distance was determined using the piece volume distribution and corridor width from unit 2. The length of the corridor was incremented from 61 to 244 m (200 to 800 ft). Because average yarder cycle times were longer, total yarding costs increased approximately \$1.50 per m^3 (\$4.20 $cunit^{-1}$) (Figure 4). The impact of longer yarding distances was partially offset by the increased area and volume yarded per corridor, which reduced the unit cost of moving the yarder between corridors.

ECONOMIC FEASIBILITY

The economic feasibility of low-volume forest biomass removals depends on the total stump-to-market costs and the market values. The relationships shown between yarding cost and piece volume also hold true for felling, limbing, and loading: it costs more to process small pieces than large pieces. This is especially true on terrain too steep for the mechanized felling and bunching machines often used to harvest small trees. With favorable yarding conditions, the estimated total stump-to-mill cost of

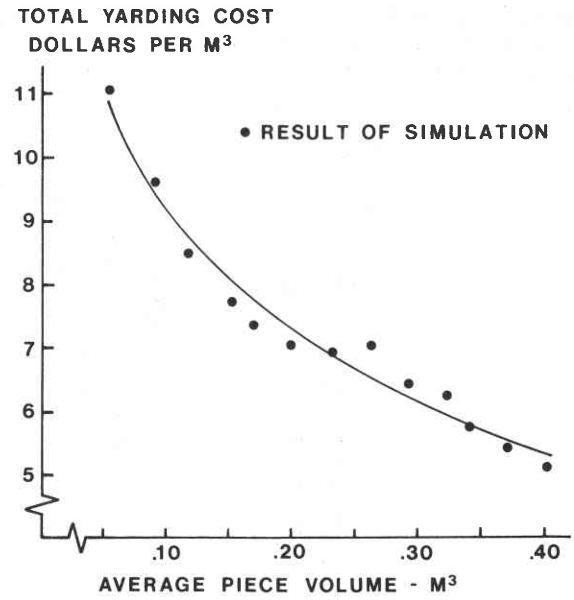

Figure 3. Simulation results showing the effect of average piece volume on total yarding cost

manual felling and limbing, yarding, loading, and hauling ranged from \$17.85 to \$25.00 per m^3 (\$50.00 to \$70.00 $cunit^{-1}$), for haul distances of 24 to 56 km (15 to 35 mi).[12] These costs exceeded the current prices of \$12.00 to \$15.00 per m^3 (\$33.00 to \$42.00 $cunit^{-1}$) generally paid for hardwood pulpwood or industrial fuelwood. Although prices of approximately \$20.00 per m^3 (\$55.00 $cunit^{-1}$) are paid for small-diameter roundwood delivered to manufacturers of wooden pallets[13] or processors of fuelwood,[14] these markets are very limited.

One alternative that could prove economically feasible would be to market fuelwood at roadside. The buyer would buck the bole-length pieces to the desired length and load them. This approach is now used where there is a high fuelwood demand for residential heating. Depending upon yarding conditions, eliminating the loading and hauling cost could reduce total costs to \$8.90 to \$14.30 per m^3 (\$25.00 to \$40.00 $cunit^{-1}$). Prices of \$9.00 to \$14.00 per 0.9 m^3 (1/3 cunit) pickup truckload would cover the cost of felling and yarding. When biomass removal is required for site preparation or regeneration, a portion of the harvesting cost might be borne by the landowner in lieu of alternative costs.

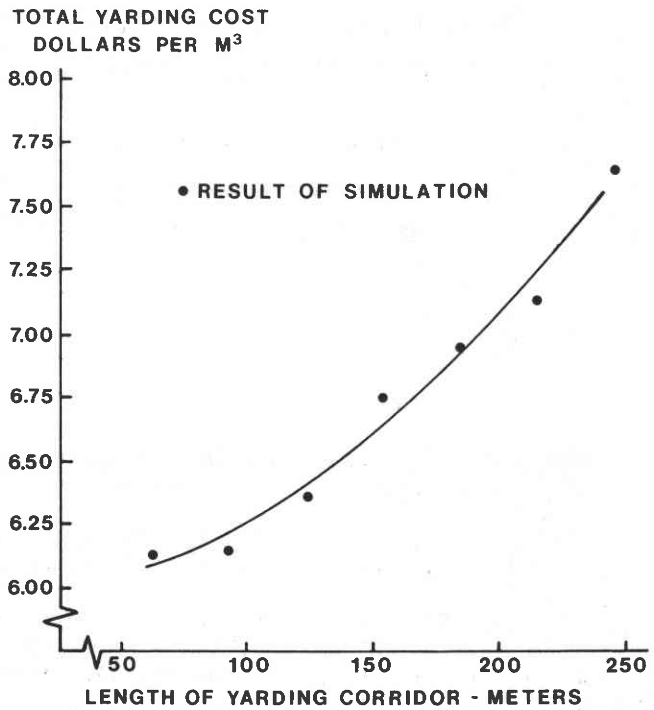

Figure 4. Simulation results showing the effect of corridor length on total yarding cost

CONCLUSION

Results from this study show that the cost of harvesting biomass with small cable yarder can be greatly reduced by using a two-person crew and yarding selectively with minimum piece-size limits. Results also show that average piece volume is the most important site-related variable affecting yarding cost and that significant variations in total yarding cost can be expected in response to changes in average piece size or yarding distance.

Because landing space on steep terrain sites and the production capacity of the small yarder are limited, biomass harvesting will often be limited to the utilization of bolewood. Difficult topography also requires costly manual felling and limbing which, coupled with loading and hauling costs, contributes to a total harvesting cost that is likely to exceed the value of the biomass removed. Marketing roundwood fuel at the logging site could be a more viable option. Environmental concerns may dictate the use of cable yarding. However, its application to low-volume biomass removals will be limited by the distance to markets, market values, the demand for residential fuelwood, and alternative site preparation costs.

Although the results from field tests and simulations such as those summarized in this paper will not provide all the answers to biomass removal from steep terrain, they should give managers the data with which to develop economic harvesting policies.

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