RP 518

Maximizing Financial Yields by Integrating Logging and Silvicultural Techniques

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Chris B. LeDoux and J. Douglas Brodie

*ABSTRACT — Substantial gains in merchantable volume yields and profits from Douglas-fir (*Pseudotsuga menziesii *(Mirb.) Franco) stands in mountainous terrain can be achieved by considering logging and silvicultural techniques simultaneously. To maximize financial yields, managers must consider not only the length of the rotation, timing of entries, and volume removal per entry but also the proper harvesting equipment, precommercial and commercial thinning treatments, and fertilizer applications. The joint returns from combinations of techniques are greater than the sum of returns from each technique applied independently.*

Young-growth forests of Douglas-fir in the mountains of the Pacific Northwest will require intensive management if they are to help meet the nation's increasing demands for wood. Such management will generally require entries into the stands when the trees are small. Timing of entries, silvicultural treatments, and equipment for cable logging must be chosen carefully to ensure a profitable operation.

Many machines are available for harvesting smallwood. Similarly, several silvicultural treatments are available for managing young stands. The problem is to match logging with silvicultural techniques so that the long-term merchantable volume yield will be increased and financial return will be maximized. In this article, various combinations of equipment and silvicultural practices are evaluated by simulation and optimization techniques.

Three models were used in the simulations and optimizations. The THIN model (LeDoux and Butler 1981) was employed to develop cost functions for various combinations of equipment, terrain, and cable configuration. These cost functions were then fed into DOPT, a dynamic programming model that determined optimum financial returns for the logging systems and silvicultural practices considered (Brodie and Kao 1979, Sessions 1979, Kao 1980). As an alternative, the same combinations of machines and silvicultural treatments were analyzed with DFIT (Bruce et al. 1977), a model for simulating or predicting yields in Douglas-fir stands. Simulation allows for variation in the timing and degree of treatments, but it does not determine optimum yields and returns on the basis of the practices and machines considered. We present both simulation and optimization runs for varying combinations of equipment and silvicultural treatments, and demonstrate the effects on logging costs, returns, and stand development for a specific site.

Equipment Combinations

Harvesting machines vary in efficiency according to terrain, average size and number of stems removed, and whether the limitations of the machine are being exceeded. *Figure 1* shows this variability for three sets of machines on mountainous terrain of moderate difficulty. The first system depicted—a small, low-investment drum set—can prebunch small logs to a central skyline corridor. The prebunched logs are later swung to a landing with a small Schield Bantam yarder. The second system—a small, relatively inexpensive, low-capacity Igland Jones Trailer Alp—is capable of yarding small logs. The third system—an expensive, medium-size, high-capacity Skagit GT3 yarder—can be used to harvest larger logs later in the rotation. The three cable systems differ in initial investment costs as well as in the size of crews required. For example, the single-drum set used for prebunching would require two people, the small Igland Jones three people, and the medium-sized Skagit GT3 a crew of four.

If machines of lower capacity and cost are selected for the initial entries, then machines are more efficiently matched to site conditions and costs of log extraction are kept low (*fig. 1*). The larger yarder is used in the final harvest where the log sizes are larger. Using small winches and small yarders with limited capacities for final harvest may result in costly equipment failures and downtime. For example, although it might appear from the figure that the Igland Jones Trailer Alp would be cost-efficient when the average stand diameter reaches 14 inches or more, logs of that size may be too large for safe handling by this machine. Conversely, using an oversized machine in the early entries may result in

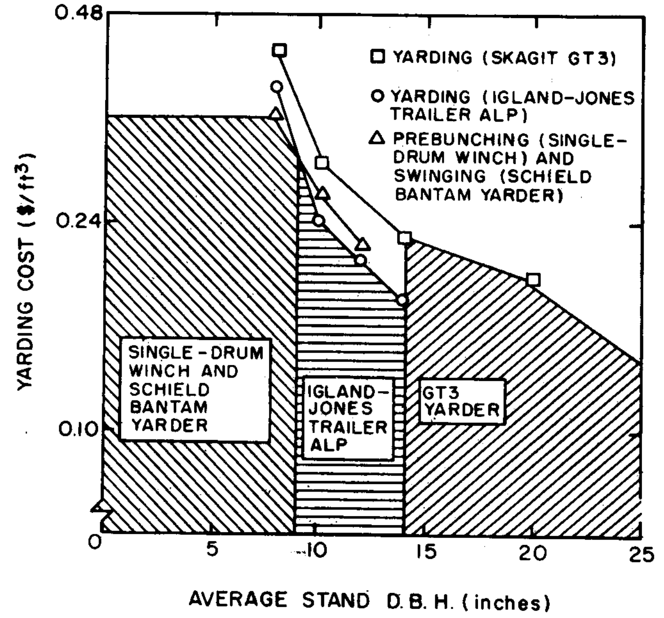

Figure 1. Comparative yarding costs for three logging systems used in thinning on mountainous terrain (30-percent sideslope, 504-foot average yarding distance, 100 trees per acre removed). Shaded regions indicate diameter range best suited for individual machines.

Table 1. Harvesting Douglas-fir by fixed entries and rotation[1] with multiple machines and with a single machine. Mean annual volume removed per acre is 154.5 cubic feet for both machine options.

Entry age	Machine configuration	Average stand d.b.h.	Stems removed per acre	Volume removed per acre	Felling, bucking, limbing cost	Yarding cost	Loading cost	Hauling cost	Pond value[2]	Cumulative present net worth per acre
Years		In	No.	Cu ft	- - - - - - - - - Dollars per cubic foot - - - - - - - - -					Dollars
				MULTIPLE MACHINES						
36	Prebunching, single-drum winch Swinging, Schield Bantam yarder	8.01	134	1,367	0.075	0.159	0.041	0.110	0.39	−281.4
51	Yarding, Igland-Jones Trailer Alp with haulback	9.60	109	1,920	.047	.253	.025	.098	.68	−169.6
60	Yarding, GT3 with 3-drum MSP carriage[3]	13.31	159	5,985	.050	.224	.018	.093	1.05	509.7
				9,272						
										Se = 613.85
				SINGLE MACHINE						
36	Yarding, GT3 with 3-drum MSP carriage	8.01	134	1,367	0.075	0.420	0.041	0.110	0.39	−321.3
51	Same	9.60	109	1,920	.047	.282	.025	.098	.68	−221.9
60	Same	13.31	159	5,985	.050	.224	.018	.093	1.05	457.3
				9,272						
										Se = 550.81

[1] *Conditions—site index, 140; real interest rate, 3 percent; minimum merchantable d.b.h., 6 inches; regeneration cost per acre, $200.*

[2] *Pond value is the price of logs of a specific species and grade when delivered to the mill.*

[3] *MSP indicates mechanical slack-pulling carriage.*

excessive costs and stand damage. Prudent selection of harvesting machinery can increase net returns.

Significant cost savings can be realized by properly matching logging machines with stand conditions at each entry. *Table 1* compares the costs of harvesting a specific stand (site index 140) by fixed entries and rotation with a combination of machines and with a single machine. Soil expectation (Se) value is used to compare returns.[1] Thinning ages and rotation age were specified at arbitrary but reasonable times. Note that a 10.3-percent gain in soil expectation is realized by matching machine capacity to log size for all entries instead of using the same high-capacity machine throughout.

Commercial Thinning

Because the analysis in *table 1* fixes rotation length and volume removal, volume and financial returns may not be optimal. If the stand depicted in *table 1* is restricted to commercial thinnings without other silvicultural treatment, then the optimal management strategy (*table 2*) can be obtained by deriving extraction costs from the THIN model, feeding them into the DOPT optimization model, and allowing for entry into the stand every 10 years. At age 30 years, a commercial thinning is scheduled when the average stand d.b.h. is 6.4 inches. This initial entry is the most difficult financially, but it frees space, in the stand, thus stimulating growth and resulting in larger logs later in the rotation.

Even with the most efficient harvesting machinery suited to the small logs produced at age 30, the initial entry is expensive and does not fully pay for itself unless future yields are taken into account. The second

Table 2. Optimum entry timing and rotation length for commercial thinning and final harvest of Douglas-fir.[1] All values except d.b.h. are per acre. Mean annual volume removed per acre is 159.4 cubic feet.

Entry age	Machine configuration	Average stand d.b.h.	Stems removed	Volume removed	Cumulative present net worth
Years		In	No.	Cu ft	Dollars
30	Prebunching, single-drum winch Swinging, Schield Bantam yarder	6.4	255	1,379	−428.7
40	Prebunching, single-drum winch Swinging, Schield Bantam yarder	9.0	150	2,082	−363.0
50	Yarding, Igland-Jones Trailer Alp with haulback	12.2	45	916	−284.1
60	Yarding, GT3 with 3-drum MSP carriage	15.2	30	997	−217.8
70	Same	18.0	45	2,848	116.4
80	Same	20.9	45	4,535	663.1
				12,757	
					Se = 731.88

[1] *Conditions—site index, 140; real interest rate, 3 percent; minimum merchantable d.b.h., 6 inches; regeneration cost per acre, $200.*

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[1] *The soil expectation value is a maximization of the present net worth of revenues minus costs from an acre of bare ground and all future stands on that acre.*

and subsequent entries all increase the cumulative present net worth. At final harvest, increases of 3.2 percent in mean annual volume per acre and 19.2 percent in soil expectation are realized by optimizing instead of harvesting by fixed entries and rotation.

Table 3. Optimal entry timing and rotation length for precommercial thinning, commercial thinning, and final harvest of Douglas-fir.[1] All values except d.b.h. are per acre. Mean annual volume removed per acre is 163.0 cubic feet.

Entry age	Machine configuration	Average stand d.b.h.	Stems removed	Volume removed	Cumulative present net worth
Years		*In*	*No*	*Cu ft*	*Dollars*
30	Prebunching, single-drum winch Swinging, Schield Bantam yarder	8.5	150	1,536	−268.8
40	Yarding, Igland-Jones Trailer Alp with haulback	11.1	165	3,391	154.8
70	Yarding, GT3 with 3-drum MSP carriage	19.9	30	2,700	565.6
80	Same	22.5	45	5,414	1,280.3
				13,041	
					Se = 1,413.09

[1] *Conditions—site index, 140; real interest rate, 3 percent; minimum merchantable d.b.h., 6 inches; regeneration cost per acre, $200; precommercial thinning cost, $90 per acre.*

Adding Precommercial Thinning

While trees are still too small to produce marketable products, they can be precommercially thinned to manage growing stock and space. The expense of precommercial thinning is weighed against the gains in yield in *table 3*, which depicts the same stand conditions as in the previous tables. A precommercial thinning to 390 stems per acre is scheduled at age 10. Because of accelerated diameter growth after this precommercial thinning, the first commercial entry at age 30 yielded trees averaging 8.5 inches in diameter, whereas entry at the same age in the stand not precommercially thinned yielded 6.4-inch trees (*table 2*). The strategy with precommercial thinning increases the cumulative present net worth at every commercial entry including the first.

At final harvest, precommercial thinning results in increases of 2.2 percent in volume and 93 percent in soil expectation over values for stands not precommercially thinned. This increased return is due to the increased gross value of products manufactured from larger trees and the increased efficiency of harvesting and processing these larger logs.

Thus, precommercial thinning is a relatively inexpensive procedure ($90 per acre) that greatly enhances the productivity of the stand. It should be thought of as an investment in the future growth of the remaining trees.

Table 4. Optimal entry timing and rotation length for precommercial thinning, commercial thinning, fertilization, and final harvest of Douglas-fir[1]. All values except d.b.h. are per acre. Mean annual volume removed per acre is 210.3 cubic feet.

Entry age	Machine configuration	Average stand d.b.h.	Stems removed	Volume removed	Fertilizer	Cumulative present net worth
Years		*In*	*No*	*Cu. ft*	*Lbs*	*Dollars*
30	Prebunching, Single-drum winch Swinging, Schield Bantam yarder	8.5	180	1,844	200	−249.5
40	Yarding, Igland-Jones Trailer Alp with haulback	12.2	75	1,868	200	−13.8
50	Yarding, GT3 with 3-drum MSP carriage	15.4	60	2,741	200	471.5
60	—	19.2	0	0	400	457.4
70	Yarding, GT3 with 3-drum MSP carriage	22.1	75	8,272	0	1,925.4
				14,725		
						Se = 2,203.74

[1] *Conditions—site index, 140; real interest rate, 3 percent; minimum merchantable d.b.h., 6 inches; regeneration cost per acre, $200; precommercial thinning cost, $90 per acre; cost of 200 lb of fertilizer (445 lb of urea = 200 lb of N), $62 per acre; cost of 400 lb of fertilizer, $118.*

Adding Fertilization

Fertilization of trees with nitrogen enhances their metabolic activity. Nitrogen increases the photosynthetic efficiency of existing leaf area and stimulates the production of new leaves. Increased leaf area allows for more efficient interception of light so that the amount of carbon fixed and available for growth is increased.

Although response to fertilizer cannot be predicted exactly, Kao's (1980) quantitative study allows fertilization treatments and their interaction with other stand treatments to be evaluated. *Table 4* shows the combined effects of precommercial thinning, commercial thinning, and fertilization with nitrogen in amounts required to optimize soil expectation of the same site shown in the previous tables. At harvest, the combined treatments yield an increase of 31.9 percent in mean annual volume and 201 percent in soil expectation when compared with the results of commercial thinning alone *(table 2)*. The combined treatments not only increase the volume yield and soil expectation, but also do so with a 70-year instead of an 80-year rotation *(table 3)*.

The gain in returns from nitrogen application is due not only to the increased leaf area efficiency but also to the interaction with the precommercial and commercial thinnings. Fertilizer is applied several times after the thinnings. The interaction of this practice with the two types of thinning produces large logs in a short time. These large logs bring in more revenue than smaller timber and are cheaper to harvest. As Kao (1980) has shown, the joint returns from all three practices are greater than the sum of returns from each practice applied independently.

Many decision-makers react more readily to presenta-

Table 5. Net cash-flow from commercial thinning and final harvest and from precommercial thinning, commercial thinning, fertilization, and final harvest of Douglas-fir. All values except d.b.h. are per acre.

Time	Average stand d.b.h.	Volume removed	Silvi-cultural cost	Current total pond value[1]	Total stump to pond cost[2]	Net cash flow
Years	*In*	*Cu ft*	- - - - - - - - - - - - - - *Dollars*	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -
			COMMERCIAL THINNING AND HARVEST			
0	—	—	−200.00	—	—	−200.00
10	—	—	0	—	—	—
30	6.4	1,379	0	700.96	−1,256.07	−555.11
40	9.0	2,082	0	1,479.04	−1,264.72	214.32
50	12.2	916	0	878.54	−532.65	345.89
60	15.2	997	0	1,188.70	−798.09	390.61
70	18.0	2,848	0	4,015.42	−1,369.28	2,646.14
80	20.9	4,535	0	7,416.12	−1,598.75	5,817.37
			PRECOMMERCIAL AND COMMERCIAL THINNING, FERTILIZATION, AND HARVEST			
0	—	—	−200.00	—	—	−200.00
10	—	—	−90.00	—	—	−90.00
20	—	—	—	—	—	—
30	8.5	1,844	−62.00	1,238.30	−1,195.90	−19.60
40	12.2	1,868	−62.00	1,791.61	−960.75	768.86
50	15.4	2,741	−62.00	3,310.65	−1,121.14	2,127.51
60	19.2	0	−118.00	0	0	−118.00
70	22.1	8,272	0	14,298.77	−2,675.41	11,623.36

[1] *Pond value is the price of logs of a specific species and grade when delivered to the mill.* [2] *Includes a hauling cost of $110 per thousand cubic feet.*

tions on the basis of current cash flow than to those based on discounted cash flow or soil expectation. Accordingly, *table 5* compares the results of commercial thinning only (from *table 2*) and precommercial thinning with fertilization (from *table 4*) in terms of current cash flow. Site conditions are as in the previous tables. From this comparison, it is clear that much of the gain from intensive silviculture comes from decreased total and unit logging costs, supplemented by increased quality and total growth. ■

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THE AUTHORS—Chris B. LeDoux is instructor, Department of Forest Engineering, and J. Douglas Brodie is associate professor, Department of Forest Management, Oregon State University, Corvallis. Mention of trade names is for identification only and does not imply endorsement by Oregon State University or the authors.