AN ECONOMIC EVALUATION OF PRECOMMERCIAL THINNING IN PREDOMINATELY PAPER BIRCH STANDS

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BEFORE TIMBER MANAGERS invest their time and money in precommercial thinnings in paper birch stands, they should know what thinning options are open to them and should have some idea of the response they might expect from the alternatives. Equipped with a knowledge of these options, the manager can select the monetary and output goals that best suit his own situation in managing paper birch stands.

A study of three precommercial thinning practices by our timber-management research division in a paper birch stand provided the necessary physical data for making an economic evaluation of some thinning alternatives. The objective of this evaluation was to determine the real changes taking place in the stand tables under the applied practices for the first 5 years and to project these stand tables for 10, 15, and 20 years after thinning. These changes were then analyzed to determine: (1) What proportion of the stands met feasible production goals?: (2) What proportion of the stands could be subject to a commercial cutting during a given period?; and (3) What proportion of the stands made selected rates of return on precommercial thinning investment during the period analyzed? Even though the whole stand was analyzed, the main emphasis was on the development of paper birch and yellow birch and their response to the thinning practices applied.

THE STUDY EVALUATED

The study evaluated was a trial of precommercial thinning practices on the Bartlett Experimental Forest in New Hampshire, in a northern hardwood stand. The study, established in 1959, consisted of three thinning practices of five ¼-acre plots each and five unthinned plots, a total of 20 plots. The plots were randomly arranged on the study area so that no bias would occur when thinning results were analyzed, hence the results would be unbiased for the area and would be representative of what might be expected elsewhere under similar conditions. The plots were remeasured every 5 years.

The stand conditions at the time of thinning and stand history were described by Marquis in 1967.[1] At the time of thinning the stand was 25 years old and contained the average number of stems per acre shown in table 1.

This stand table illustrates the tree distributions concerned with in this evaluation. They are the averages derived from all 20 plots in the experiment. On all the sample plots, tree numbers ranged from 3,900 to 4,200 trees per acre, and their distributions by species and size were similar to those shown in table 1. Individual plots did range above and below these averages, but differences were minor.[2]

The purpose of thinning these stands was to improve the growth and development of selected crop trees. Crop trees were chosen at

[1] Marquis, David A. CLEARCUTTING IN NORTHERN HARDWOODS: RESULTS AFTER 30 YEARS. USDA Forest Serv. Res. Paper NE-85. 13 pp., illus. NE. Forest Exp. Sta., Upper Darby, Pa. 1967.

[2] After random assignment of plots to treatments, it was found that the heavy thinning plots had fewer paper birch trees in the 5- to 8-inch d.b.h. classes than the other three treatments (61 versus 90 to 104). Since paper birch represents the major part of the yields reported here, this initial difference in stocking has tended to reduce the early yields on the heavy thinning plots more than they would have been had all plots had equal initial stocking. No adjustments have been made for this difference in the data and discussion.

the rate of about 400 trees per acre. Most crop trees were either paper birch, yellow birch, white ash, or sugar maple, although exceptional individuals of other species were also included. Four distinct thinning alternatives were tested.

1. *No thinning*.—These plots were left undisturbed to develop naturally. They constitute a control or standard against which to measure the responses of other groups of plots.
2. *Light thinning*.—Trees competing with individual crop trees were noted and the one offering the greatest competition was removed in this form of precommercial thinning.
3. *Species thinning*.—Aspen, pin cherry, and striped maple were eliminated in this thinning procedure. Red maple sprout clumps were thinned. The relationship of thinned trees to crop trees was not considered.
4. *Heavy thinning*.—All trees competing directly with the crop trees were removed.

In addition to the beginning tally, the quantitative information provided by the experiment included a treatment record of the species and sizes of trees treated, an after-treatment inventory of the stand, a stand table 5 years later, and growth data from selected individual trees, which covered all tree sizes and species.

PROJECTED STAND DEVELOPMENT

Stand tables were projected for each plot to 10 years after thinning or a stand age of 35 years, to 15 years after thinning or a stand age of 40 years, and to 20 years after thinning or a stand age of 45 years. To make these projections, background information about diameter growth and mortality had to be acquired so that reasonable assumptions could be made about the projections.

Characteristic growth patterns were developed for each species for each thinning practice. For example, the diameter growth for paper birch appears in table 2.

Information like that shown in table 2 was used by assuming that a tree would maintain its first 5-year growth rate for the next three 5-year periods. For example, a 6-inch paper birch tree in the heavy thinning plots grew 1.13 inches in the first 5-year period, so we projected it to grow at this rate for the next three 5-year periods.

Basic assumptions for mortality estimates were based on a critical examination of stand-table changes between the after-treatment stand table and the one 5 years later to determine the magnitude of the mortality for each species and in what size classes it occurred. On the basis of this examination we assumed that:

1. Relative mortality would continue on a plot/species basis and would be measured

Table 1.—*1958 average number of trees per acre on all thinning plots, by species and diameter class*

Diameter class (inches)	Paper birch	Yellow birch	White ash	Sugar maple	Red maple	Beach	Aspen	Conifers	Others [1]	Total trees/acre
1	85	248	32	807	80	759	1	25	205	2,242
2	112	142	26	159	48	213	5	23	287	1,015
3	78	61	18	40	25	41	7	6	179	455
4	61	20	13	8	18	3	8	3	70	204
5	41	2	3	1	3	1	7	1	15	74
6	21	1	1	1	1	—	10	—	2	37
7	7	—	—	—	—	—	4	—	1	12
8	1	—	—	—	—	—	3	—	—	4
9	—	—	—	—	—	—	1	—	—	1
10	—	—	—	—	—	—	1	—	—	1
11	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—
14	—	—	—	—	—	—	—	—	—	—
15	—	—	—	—	—	—	—	—	—	—
Total	406	474	93	1,016	175	1,017	47	58	759	4,045

[1] Others consisted mainly of pin cherry and striped maple.

by the percentage of trees that died in the first 5 years.

2. Mortality would occur in the smallest size classes first.

3. No mortality would occur after trees had reached 6 inches d.b.h.

It was felt that this deduction for mortality would account for normal attrition of the whole population of stems. Essentially this phase of mortality is handled as a risk. Another kind of mortality—involving insects, disease, fire, and weather as causative agents—we considered to be an uncertainty; so we ignored it.

The stand-table projection was made by using tree-diameter-movement ratios developed from the growth data, using the method described by Davis.[3] After the stand was projected, the mortality was subtracted according to the rules stated earlier. Our procedure then was to begin with the stand 5 years after thinning. We projected all the trees for the next 5 years, using the tree-diameter-movement method and then deducted mortality to give us the stand table at the end of the 10-year period. This was repeated for the 15- and 20-year projections. It was done for each species and each plot.

Timber volumes, measured in cords, were estimated by multiplying numbers of trees shown in the stand tables by appropriate volumes. Local volume tables were made by applying height-diameter relationships for the Bartlett Experimental Forest to the standard volume tables of Gevorkiantz and Olsen[4] for northern hardwoods to a 4-inch top inside bark. Later these were converted to volumes to a 6-inch top for estimating outcomes for higher-grade products.

The final product of our projections was the volume of each plot by species and size classes, in cords, to a 4-inch top and a 6-inch top. With this as basic information we were ready to proceed to economic analyses and evaluations.

These projections must be reasonable if the rest of the evaluation is to be worthwhile. No one knows better than we do how far we have come from those plots on the ground, and how easily the results of assumptions about growth and mortality can pyramid into collosal errors in 20 years of projections. We took steps to be sure our results were reasonable. First we developed our procedure, using the first 5 years as a trial and compared our projections with what actually happened. Then, as we proceeded with the final projections, we tested them against available data for paper birch stands in these ages.

Since the form of the projected yields conforms to that of the independent set of data, and the divergences of yield for each thinning practice when compared to others is logical, the synthesized yields from the projection system are judged satisfactory for our purposes.

ECONOMIC ANALYSIS

An economic analysis should answer economic questions such as achieving production goals at least cost, or assessing flexibility for future actions, or maximizing benefits. In our economic analysis we consider the forest-management-research information as a series of performance tests. We test the performance of the thinning methods with economic measures. We pose economic questions, describe their solution, and present the results.

Achieving Output Goals

All outputs were measured in cords per acre. Four production goals were set; three products were recognized, and we asked first what proportion of the plots for each thinning

Table 2.—The diameter growth in inches of paer birch by diameters and precommercial thinning method for the first 5 years after thinning

D.b.h. (inches)	Thinning method			
	None	Light	Species	Heavy
2	0.11	0.20	0.44	0.53
3	.36	.36	.55	.63
4	.62	.64	.68	.72
5	.82	.88	.85	.94
6	.98	1.06	1.06	1.13

[3] Davis, Kenneth P. AMERICAN FOREST MANAGEMENT. 482 pp. McGraw-Hill Book Company, Inc., New York, 1954.

[4] Gevorkiantz, S. R., and L. P. Olsen. COMPOSITE VOLUME TABLES FOR TIMBER AND THEIR APPLICATION IN THE LAKE STATES. U.S. Dep. Agr. Tech. Bull. 1104, 51 pp., illus. 1955.

practice met the goals. Goals of 3, 5, 10, and 20 cords per acre were established as being reasonable harvesting limits for different management objectives and harvesting methods.

The results of each thinning plot were tested at each 5-year period to see if they met these goals for: (1) all roundwood to a 4-inch top; (2) paper and yellow birch to a 6-inch top; and (3) paper and yellow birch to a 6-inch top, with at least 20 trees 12 inches d.b.h. and larger.

These specifications represented: (1) reasonable merchantable limits for pulpwood; (2) reasonable limits for low-value boltwood; and (3) reasonable limits for medium-value boltwood with a modest proportion of veneer sizes.

Since there were five plots for each thinning method, each plot represents 20 percent of the population. If all five plots meet our criterion, 100 percent of them achieved the production goal. The results of this procedure are posted in table 3.

Cost information is needed to appraise the least-cost way of attaining these goals. Cost estimates were based on the tally of live trees that were killed on each plot during the thinning operations, but not marking or supervisory costs. The number of diameter inches treated in each case was determined from this tally. Thinning costs were estimated at 1 cent per diameter inch.

Table 4 shows the costs for thinning the plots with these assumptions. This table shows that costs per acre were materially lower for the light thinning method. The heavy and species thinning were 70 to 100 percent higher. Of course the no-thinning or let-it-grow alternative does not require precommercial thinning investment, so it is least expensive of all.

These cost differences are large enough and the pattern of goal achievement is clear enough that a vigorous least-cost analysis was not needed for our purposes. We see by inspection that no thinning is the least-cost option for producing cordwood to a 4-inch top at all ages. When we consider the higher value products exemplified by the data in the lower section of table 3, a light thinning shows up best because none of the unthinned plots met 5- or 10-cord goals. These views do not change even if we set a probability limit to our inspection such as not considering a goal unless say 60 percent of the plots met the goal.

Tables 3 and 4 provide preliminary information for forest managers to use for their own special cases. A forest manager constrained by acreage limitations, the timing of cuts, and product requirements can use such information in a simulation program or linear program to calculate an optimum precommercial thinning solution for his particular problem. For these purposes the manager can equate the cost of achieving the goals by dividing the average cost by the percentage of plots that met the goals.

Flexibility for Making a Partial Commercial Cutting

Many managers may want to see an early intermediate commercial cutting as the fruit of a precommercial thinning investment. We analyzed the data with this in mind. We asked: "When do we gain the flexibility to

Table 3.—*Achieving output goals: percent of plots meeting selected harvest criteria by age and thinning method*

Harvest criteria (cords/acre)	Age in years: 30				35				40				45			
	Light	Species	Heavy	None	Light	Species	Heavy	None	Light	Species	Heavy	None	Light	Species	Heavy	None
ALL TREES TO A 4-INCH TOP																
3	100	80	40	80	100	100	100	100	100	100	100	100	100	100	100	100
5	60	60	20	80	100	100	100	100	100	100	100	100	100	100	100	100
10	—	—	—	—	60	60	20	60	100	100	100	100	100	100	100	100
20	—	—	—	—	—	—	—	—	40	60	—	20	60	80	100	80
PAPER BIRCH AND YELLOW BIRCH TREES TO A 6-INCH TOP																
3	80	60	20	60	100	80	60	80	100	100	100	100	100	100	100	100
5	20	20	—	—	80	60	40	80	100	80	60	80	100	100	100	100
10	—	—	—	—	—	—	—	—	20	60	40	40	80	60	40	80
20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PAPER BIRCH AND YELLOW BIRCH TREES TO A 6-INCH TOP WHEN AT LEAST 20 PER ACRE ARE 12 INCHES D.B.H. AND LARGER																
3	—	—	—	—	—	—	—	—	20	—	—	—	80	40	20	—
5	—	—	—	—	—	—	—	—	20	—	—	—	80	40	20	—
10	—	—	—	—	—	—	—	—	—	—	—	—	60	20	20	—
20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

make a commercial cutting and still maintain recommended stocking levels of paper birch?" The B stocking level in *A Silvicultural Guide for Paper Birch in the Northeast* [5] was used as a criterion for judging stocking success after a commercial cutting.

The number of paper birch trees 6 inches and larger was tested against this criterion. We selected a 5-cord-per-acre commercial cutting as a reasonable goal. The results indicated that we could make a commercial cutting to a 4-inch top (pulpwood) and meet the criterion for B-level stocking. Table 5 shows the proportion of the plots that can sustain a 5-cord cutting to a 4-inch top and leave enough paper birch 6 inches d.b.h. and larger to meet the B level stocking criterion.

From table 5 we see that this intermediate cutting goal is probable 15 years after thinning at age 40 under the light and species thinnings; and the light thinning is less expensive and performs better. Even these results would not be accepted if we required a probability limit of 60 percent before considering the results to be successful. The intermediate cutting goal was achieved for all four methods at age 45, and their cost effectiveness would rank then (1) no thinning, (2) light thinning, (3) species thinning, and (4) heavy thinning.

Achieving Goals for the Precommercial Thinning

Price information for estimating values for the different products is required for determining rate of return to the thinning investment. The specifications used earlier for production goals were established with unit values in mind. The unit prices themselves were selected by matching specifications and quotations from the wood-procurement departments of wood-products manufacturers with the potential product specifications of the stands with which we were dealing. The following price schedule was decided upon:

Forest Specifications	*Potential products*	*Unit price*
All trees to a 4-inch top.	Pulpwood.	$2/cord
Trees to a 6-inch top; paper and yellow birch only.	Birch boltwood.	8/cord
Trees to a 6-inch top; the stand must have 20 trees per acre 12 inches d.b.h. and larger. Paper and yellow birch only.	Birch boltwood, with some veneer potential.	14/cord

These unit values are benchmark values — they are good for generalizing because they are in the right neighborhood but not especially good for any particular sale area.

The number of cords per acre for each plot at each 5-year interval was multiplied by the above unit prices to determine the total plot value per acre. The five thinned-plot values for each thinning practice were then compared with the unthinned-plot values to see how much the practices had increased the stand value above the unthinned stand values. In all we made 25 comparisons for each thinning practice, a total of 75 comparisons for the three practices.

Table 4.—*Thinning costs for the precommercial thinning tests at 1 cent/diameter inch removed*

Replication	Costs per acre		
	Species	Light	Heavy
1	$19.50	$12.40	$22.80
2	19.00	10.70	19.80
3	18.60	10.60	19.60
4	17.40	10.50	18.60
5	14.70	10.30	18.00
Average	17.84	10.90	19.76

Table 5.—*Percentage of plots that sustain a 5-cord intermediate cut of material to a 4-inch top and meet recommended stocking levels of paper birch*

Precommercial thinning method	Age of stand (years)			
	30	35	40	45
None	0	0	0	60
Species	0	0	20	40
Heavy	0	0	0	40
Light	0	0	40	40

[5] Marquis, David A., Dale S. Solomon, and John C. Bjorkbom. A SILVICULTURAL GUIDE FOR PAPER BIRCH IN THE NORTHEAST. In press, NE. Forest Exp. Sta., Upper Darby, Pa., 1969.

The comparisons showing positive value differences were then divided by thinning costs to determine the value ratio between a thinned plot and each unthinned plot. Each ratio was then used to determine the rate of return.[6] The percentage of these tests that met a rate of return criterion then was calculated. The results of these calculations are shown in table 6.

For example, the 48 percent at the right-hand side of the top row (table 6) means that 48 percent or 12 out of 25 possible comparisons showed a positive return at age 45 in a combination pulpwood and low-value boltwood market. In 52 percent of the cases the no-thinning alternative showed up better than the thinning practices. The rate of return criteria were selected to reflect different economic points of view. Zero and 2 percent were used for those in departmentalized or multiple-use situations; 4 and 6 percent were used to reflect the usual (in a historical sense at any rate) rates of return from alternative investments; the 10 percent was included to represent a highly attractive investment return.

[6] Rate of return $= (1 + i)^n = \frac{V_n}{V_o}$. The symbol "i" = interest rate; n = period of years; V_n = income due after n years; and V_o = present capital value of investment. For example, if the thinning practice cost \$18.00/acre and the stand value/acre after 20 years was \$90.00/acre, then $\frac{\$90.00}{18.00} = \frac{V_n}{V_o} = 5.0$. From the interest tables, $1.084^{20} = 5.019$, or the rate of return equals a little less than 8.4 percent.

EVALUATION OF PRECOMMERCIAL THINNING ALTERNATIVES

In this evaluation 245 separate analyses were made. They really do not lend themselves to tabulation as a summary evaluation because the table would be too long and cumbersome. We can describe the general performance characteristics of these thinning alternatives. And we can propose a method so that the quantitative data can be helpful to a forest manager who is trying to decide what to do in his particular case.

NO THINNING appears best when roundwood to a 4-inch top is the product desired in the shortest possible time.

LIGHT THINNING may be preferred when an early future commercial cutting is desired, or when paper birch to a 6-inch top is the goal, or when an early return to the thinning investment is desired.

Table 6.—*Achieving rate of return goals for the precommercial investment: percentage of comparisons meeting selected rates of return on the precommercial thinning investments*

Treatments compared	Potential market: Pulpwood, \$2/cord, at age— 45	Boltwood \$8/cord, at age— 30	Boltwood \$8/cord, at age— 35	Boltwood \$8/cord, at age— 40	Boltwood \$8/cord, at age— 45	Boltwood \$14/cord, at age— 45	Pulpwood and boltwood, \$2/cord and \$8/cord, at age— 40	Pulpwood and boltwood, \$2/cord and \$8/cord, at age— 45
			0 PERCENT RATE OF RETURN					
Species vs. none	52	20	52	64	64	76	56	48
Heavy vs. none	0	0	8	24	36	44	24	28
Light vs. none	24	20	44	52	44	64	44	44
			2 PERCENT RATE OF RETURN					
Species vs. none	40	20	48	64	64	76	64	48
Heavy vs. none	0	0	8	24	24	36	20	28
Light vs. none	16	20	40	52	40	64	44	44
			4 PERCENT RATE OF RETURN					
Species vs. none	16	20	40	56	56	76	60	44
Heavy vs. none	0	0	8	20	16	28	16	12
Light vs. none	4	20	32	40	36	60	36	36
			6 PERCENT RATE OF RETURN					
Species vs. none	0	20	28	44	48	72	44	24
Heavy vs. none	0	0	8	16	8	24	12	8
Light vs. none	0	20	20	32	24	60	28	20
			10 PERCENT RATE OF RETURN					
Species vs. none	0	20	12	12	8	60	12	4
Heavy vs. none	0	0	8	8	0	4	0	0
Light vs. none	0	20	16	20	8	44	20	4

SPECIES THINNING achieved the best record for meeting usual rate-of-return goals, though the flexibility for a commercial cutting and the possible attainment of unusually high rates of returns for this option were slightly higher than those for light thinning.

HEAVY THINNING performed poorly for the first 15 years but had nearly closed the gap in some respects in 20 years and shows promise of outperforming the others in the future. If only one cultural practice is being contemplated for a paper birch stand, it may have merit with respect to any of the criteria in the long run.

The woodland manager planning a precommercial thinning investment under the conditions described here needs to decide how much time he can allow to elapse before getting substantive results from the investment and the product and market situation he may find himself in at that time. Using these (time, product, market) as restraints, he can array the results of these performance tests to help him decide which course of action suits him best.

An example: The manager seeks to use the performance-test data to help guide him for 10 to 15 years in the future. He expects the present boltwood market to persist. He is willing to use the low value quoted, and feels he can thin at the costs used here. He arrays the performance test data as shown in table 7.

With this information, he would probably discard the heavy thinning as not being fruitful in his planning time horizon. He would select the light or species thinning if he were most interested in the 15-year horizon, or the light or species thinning if most interested in the 10-year time span. He could still select the no-thinning alternative if he were not satisfied with expected returns under the thinning practices.

Table 7.—*Tested outcomes of precommercial thinnings for boltwood production, in percent success*

Thinning treatment	5-cord goal?	Commercial cut feasible?	Recover thinning costs?	4-percent rate of return on thinning investment?	10-percent rate of return on thinning investment?
			IN 10 YEARS		
None	80	0	—	—	—
Light	60	0	44	32	16
Heavy	32	0	8	8	8
Species	68	0	52	40	12
			IN 15 YEARS		
None	80	0	—	—	—
Light	72	40	56	44	20
Heavy	52	0	24	24	8
Species	68	20	68	64	12

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