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By

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ABSTRACT

Data from growing, sawing, and selling lumber from pruned white pines show that returns on invested costs at rates of at least 6% compound interest can be obtained if annual rates of diameter growth of 0.25 inches or better can be maintained. In an extreme case this was even true of a tree that grew for 62 years after pruning, and attained a conversion-return value of nearly $600 and 27 inches D.B.H. If the crown of a model tree is allowed to expand without restriction, at a rate of 1 foot of diameter annually, the yearly rate of stem diameter growth becomes 0.5 inches; on such a tree a compound interest return of 13% is sustained for at least 30 years after pruning and the tree grows to 22 inches D.B.H. Rapid growth did not produce any lumber that warped or developed other undesirable characteristics during kiln drying and subsequent manufacturing. Methods were developed for predicting the value and volume of clear lumber in pruned logs.

INTRODUCTION

The high value of clear lumber of eastern white pine (*Pinus strobus* L.) has made it the object of pruning research for many decades (R.W. Foster, 1957; Funk, 1961). However, the practice of pruning has been hampered by concern over whether the final product would be valuable enough to give adequate returns on the high cost of the operation.

It has been stated often that good financial results depend upon rapid diameter growth of the pruned trees (Hawley and Clapp, 1935, 1942; C.H. Foster, 1964; Allen, 1964). An economic study involving actual grade recovery by Fedkiw, Hopkins, and Stout (1960) indicated acceptable returns on investments even from trees that had grown moderately well for 19 years after pruning. There has sometimes been the fear that excessively rapid growth might somehow impair the quality of the lumber. This study was undertaken to examine some of these ideas empirically, with actual white pines and the sale of lumber cut from them. The chief purpose was to determine the effect of different rates of growth on financial returns.

Lumber output in terms of grade and value was determined from sawing and processing of individual pruned trees. This part of the study was similar to that of Ostander and Brisbin (1971) in which log grades were established for unpruned white pine. Rates of compound interest earned were calculated on (a) investments in treatment and (b) value of the growing tree. A few unpruned trees were analysed similarly. Comparisons were also made between trees that had grown fast because of very heavy thinning and those that had grown more slowly under regimes of lighter thinning. These results were used to design a thinning schedule which optimizes returns on investments in thinning and pruning by causing tree crowns to expand without restriction.

METHODS

Since the chief purpose of the study was to compare the effects of different rates of diameter growth after pruning, studies were made of trees from four sets of stands that had been subjected to very different regimes of thinning. The pruned trees from each stand were picked to include the full range of rates of growth of such trees. Because of problems during logging and processing it was not possible to reconstruct all of the trees and logs.

The Tree Study described in a later section (see Table 4) dealt with those whole trees for all merchantable logs could be reconstructed. The Log Study included some reconstructed logs from certain trees that could not be completely reassembled.

Two sets of stands were in central Massachusetts. Thirteen complete trees came from "Rapid-Growth Stands." These were natural stands at the Green Diamond Forest that had been pruned in 1968-73 and then heavily thinned at frequent intervals in an effort to maintain green crowns above the pruning zones. The "Thinned Plantations," the source of 10 trees, were planted in 1936 on lands of the (Boston) Metropolitan District Commission; they had been pruned and heavily thinned once in 1965 as part of a study by Hunt and Mader (1970) also reported upon by Stone et al. (1985).

Two stands had originated on abandoned farms before 1900 at the Yale-Toumey Forest in southern New Hampshire. Six trees came from a "Heavy 1938 Release Stand" and had been left isolated by the uprooting of all of their neighbors during a hurricane in 1938; four of these these trees had been pruned near the time of release. An "Old Conventionally Thinned Stand" had been lightly thinned twice after pruning in 1953 or later; 14 trees came from this stand. All of the stands were on moderately moist sites with 50-year site indexes approximating 70 feet.

All of the pruned trees had been pruned to at least 12 feet and a few to 24 feet; the most common pruned length was 16 feet.

The trees were cut during the spring of 1989. Logs were bucked to varying lengths and sawn to different thicknesses in patterns designed to maximize lumber recovery in boards thicker than 1 inch. Sawing was done on a modified Sanborn Minimax sawmill with a band-saw with 1/8 inch kerf to board thicknesses ranging from 0.9 to 2.5 inches. The centers of some logs were sawn into timbers 4"x4" or thicker; usually this was done when it seemed possible that shake might develop if the central core was sawn into boards. All boards better than No. 5 Common were put on accurately aligned stickers and kiln dried. Every piece was indelibly numbered to enable reconstruction of each log and tree.

The products were sorted and graded after drying to the standards of the Northeastern Lumber Manufacturers Association (1986a,b).

The lumber was sold, mostly in small lots, each of uniform grade, to establish actual wholesale values by grade. These are shown as conversion returns (*not* as total wholesale prices) in Table 1. Conversion return for each grade was determined by subtracting the processing costs (which included 10% allowance for profit and risk), shown in Table 2, from the wholesale lumber values. The values of conversion return were, in other words, determined by ways generally used in stumpage appraisal. Costs were assumed to be high not only for the intensive mill processing but also for the careful logging required in frequent thinnings. The wholesale prices can be determined by adding the values of Table 1 to the costs of Table 2.

For purposes of the study, all of the logs were actually sawn for grade, even though it was clear that this would cause many small or poor logs to have negative values. Such logs would, in actual practice, be sawn by faster and less intensive methods and seldom have negative values. To correct for this, if any log at least 8.5 inches in small-end, inside-bark diameter had a conversion return value of less than $0.025 per board foot, it was revalued at the $0.025 rate. However, this readjustment was not made to the value of any parts of whole logs with average value greater than $0.025 per board foot, because it was assumed that such logs would have been sawn by the more expensive and intensive method. This meant that some boards and timbers cut from those logs continued to have the negative values of conversion return shown in Table 1.

Table 1. Conversion return values in cents per board foot for different grades, thicknesses and widths of lumber; same for all lengths of 6' or more.

Thickness	0.9"	1"	1.25"	1.5"	2"	2.5"
Grade						
		3-10" Widths				
C+ Select	80	80	110	136	186	226
D Select	30	30	50	66	86	106
1&2 Common	-5	5	25	31	51	71
3 Common	-15	-5	15	21	31	51
4 Common	-25	-15	-5	11	21	31
5 Common	-25	-15	-15	-15	-15	-15
#1 Furn.	-25	-25	-15	-19	6	46
#2 Furn.	-25	-25	-15	-19	6	46
		11-15" Widths				
C+ Select	130	130	160	186	216	246
D Select	80	80	100	116	136	156
1&2 Common	15	25	75	91	111	131
3 Common	5	15	35	41	51	81
4 Common	-5	15	25	31	51	76
5 Common	-15	-15	-15	-15	-15	-15
#1 Furn.	-5	15	25	31	51	76
#2 Furn.	-15	5	15	21	41	71
		16+" Widths				
C+ Select	230	230	260	286	316	346
D Select	180	180	200	216	236	256

Common & Furniture: same as 11-15" widths

Timbers (all widths, by smallest thickness)

<4.1"	6-8"	10-12"
-17	-7	3

Table 2. Costs of harvesting and processing, dollars per thousand board feet of lumber tally, including 10% allowance for profit and risk.

Logging	120
Trucking	30
Milling	300
Kiln drying	
2+" thick	220
<2" thick	180
Storage	35
Sorting	35
Totals	
2+" thick	740
<2" thick	700
Green timbers	520

A thin cross-section was cut from the top end of each log to enable measurement of 5-year increments of small-end, inside-bark diameters. Measurements made along maximum and minimum radii were averaged for this purpose.

All financial analyses were made in terms of the costs and product values of 1989 in order to eliminate effects of both inflation and any changes in real prices. This means that the financial results would be the same so long as all costs and the price-cost relationships of Tables 1 and 2 continue to remain proportional to each other.

Compound-interest returns were determined in two different ways. One involved calculating rates of interest earned on money actually invested in the treatment and management of each sample tree. The other involved estimating, for 5-year periods, compound interest earned by a tree on the value that it had at the beginning of each period.

Several components of cost were included in determinations of internal rates of return on actual out-of-pocket investments. It was presumed that pruned trees would be grown to pruning size beneath overstory trees that would provide shelterwood regeneration and weevil protection as well as income necessary to offset per-acre holding costs. It was assumed that such overstory trees would be harvested shortly before the time of pruning. However, a cost of $1 per tree for release from hardwood competition was carried at compound interest starting from 15 years before the pruning year. A similar cost of $2 per tree for precommercial thinning was carried from a time two years before that of pruning. The cost of pruning was taken as $0.20 per running foot. In some cases, the time of pruning was not precisely known from records and was determined from measurements of the thickness of clear shell at the small ends of logs. These cost estimates were based on actual 1989 costs of performing such work, but in the high range of such costs.

An annual cost for management expenses and property taxes of $3 per acre was also assessed on the number of square feet covered by each tree in each year. These annual charges were carried at compound interest from a time two years before the pruning year. It was assumed that such charges before that time would be borne by the overstory trees harvested two years before the pruning year. This cost was included partly to take account of the fact that fast-growing trees occupy more land area than slow-growing ones. Management costs are also part of the out-of-pocket investment in growing the trees.

With unpruned trees all costs except for those of pruning were included. Annual charges were carried for the same periods as pruned trees in the same stand.

The areas occupied by each tree, i.e., crown projection areas (CPA), were determined from estimates of DBH and total height and the following equation of Seymour and Smith (1987):

$$CPA = 1265\, D^{3.589}\, H^{-2.514} \qquad \text{Eq. 1}$$

This equation was based on a study of the relationship between total stem volume and the cumulative volume of all space ever occupied by the crown of the tree. It was developed as a means of formulating thinning schedules such as the one presented in this study; some of the data used came from the Heavy 1938 Release Stand.

Return on growing stock was determined by calculating the compound interest earned by each tree on its own initial stumpage value for each 5-year interval starting with the time of pruning. Tree values for each interval were based on determinations of (a) the volume of D Select and better lumber, (b) the value per board foot of such lumber, and (c) the volume of all knotty lumber valued at $0.025 per board foot. The more detailed analysis of lumber values employed in analysis of 1988 tree values was not used because there were no actual lumber recovery data for the earlier times.

On the basis of the data from this study, the relationships between sizes of trees and those of stems shown in Equation 1 were used to construct a model for growing an "ideal" tree which would produce optimum return on investments in growing it.

RESULTS OF LOG STUDY

There were no important differences between total lumber tally and the International 1/4-inch Rule, except for some overrun in small logs. In other words, cutting many boards thicker than 1 inch and using a band-saw with 1/8-inch kerf did not produce significant overrun.

It was verified that total volume of D Select and Better lumber in a log could be determined by subtracting the board-foot volume of a square timber with thicknesses equal to the small-end, inside-bark diameter at time of pruning from total board foot volume (International 1/4-inch Rule). The fact that Select grades allow some knots on the poorer face of boards obviates the necessity of allowance for the healing over of pruning wounds. The International Rule counts short boards cut from large ends of logs as was done in this study.

It should be noted that estimates of lumber values (Table 1) are the same for all lengths; only those pieces that were at least 6 feet long were counted in this study.

The thicker each clear shell and the larger each log, the greater was the amount of thick or wide clear stock that could be cut from the log. The value in cents per board foot of Select lumber (CLVAL) in pruned logs was found to be related to the radial thickness in inches (CLRSHL) of the clear shell of wood outside the knotty core and the square of the inside-bark diameter (DIB) in inches at the tip of pruned log. The equation, based on 57 logs, is:

$$\text{CLVAL} = 23.52 + 13.81\ \text{CLRSHL} + 0.08\ \text{DIB}^2 \qquad \text{Eq. 2}$$
$(r^2 = 0.417)$

The butt log with the highest average value, $1.39 per board foot, was a log 21 inches inside bark at the small end, pruned in 1936 in the Heavy 1938 Release Stand; it had a high proportion of wide, thick boards. The highest such values for pruned logs from the Rapid Growth Stand ranged from $0.31 to $0.46 in logs of 13-16 inches of diameter and pruned 15 to 20 years ago. These logs had no significant zones of black-knotted wood and were large enough that some thick Select grade boards could be sawn from them. The same was true of the best plantation log. It had come from a heavily thinned plot and had some wide, thick D Select boards; it was valued at $0.78 per board foot. In later sections of this report it is shown that increases in log values associated with rapid growth beyond the 16-inch log diameter can continue to show good compound-interest returns to at least 20 inches of small-end log diameter. During that period, values per board foot of the butt logs could grow to equal those of the best log described here.

One complicating source of variability in average board-foot values of logs was the fact that the centers of some were sawn into timbers, either at medium prices for post and beam construction or at negative conversion returns for landscape ties. Both categories were lumped and valued as landscape ties, so the total value of these logs was penalized substantially. For example, a central timber of 6"x8"x16" had a conversion return value of -$4.48; this slightly more than offset the value of one C Select and Better board 1"x4"x16". The same central cant sawn into 3 pieces of #4 Common 2.5 inches thick would have had a return of $18.60 or $23.08 more. If the pieces were #3 Common the difference would have been $34.98.

Many such logs had centers sawn into timbers because they came from two stands with a high incidence of shake in the knotty cores. The trees involved were tall, slow-growing ones with small crowns atop stems that did not have much taper. It is suspected but cannot be proven that the ring-shake in such trees developed when they swayed widely during severe windstorms. The effect of this on the total values of logs was much greater with unpruned logs than pruned ones.

Red-knotted logs cut from within the live crowns of trees had slightly higher conversion returns for given sizes than black-knotted logs on which branches had died. However, a more important source of variation in value of unpruned logs lay in whether the red-knotted centers could be sawn into boards 1.5 inches or more thick. Such boards command good prices for furniture stock.

There was no significant amount of degrade from warping, twisting, or cupping of lumber except for that associated with compression wood; there was none that could be related to the rapid diameter growth of some of the trees or to juvenile wood. However, there was no assessment of strength properties. Almost all of the pruning wounds healed without any bark or pitch pockets extending more than one inch from the cut end of the branch.

The fundamental effect of clear shell thickness and log diameter would hold even if inflation caused prices and costs to change, provided that the general pattern of wood processing, utilization, and valuation used in this study continues to prevail.

From the information at hand, it is possible to estimate parameters for determining conversion-return values of logs with known small-end diameters of knotty core and inside-bark dimensions. Estimates of the key parameter, value per foot of log-length, are shown in Table 3. Values of Select lumber (D grade and better) are calculated from Equation 2. These calculations are based on the International Rule for 1/4-inch kerf and and the appropriate cross-sectional areas of the small ends of 16-foot logs. Values of the multiplier are slightly smaller for shorter logs and greater for longer ones. The conversion return for knotty core material is estimated as 2.5 cents per board foot, and it is assumed that board-foot volume of knotty-core material will be taken as that of a square timber as thick as the knotty core.

It is not easy to correct information such as that of Table 3 for changes in costs and prices. One standard technique is that of using the price of the best common grade of lumber as the index value. In this case, the conversion return value of #1&2 Common is 25 cents per board foot for 5/4 lumber in boards up to 10 inches wide. If one estimated that the value of this category went up 3 cents to 28 cents, i.e., by 12%, then all other values in Table 3, including the negative ones should be multiplied by 12%. This adjustment would be based on the presumption that all costs and prices remain proportional to each other.

Table 3. Conversion-return value, in cents per foot of log length, for pruned logs of different radial thickness of clear shell.

	D.i.b., small end (inches)								
Clear-shell thickness (inches)	10	11	12	13	14	15	16	17	18
3	202	223	232	254	264	287			
4	324	378	419	477	521	584	599	620	698
5			584	685	771	884	940	1023	1128

RESULTS OF TREE STUDY

The data of Table 4 for the four different kinds of stands are ranked in decreasing order of the rates of compound interest earned by the investments in treatment of each tree. In the case of three kinds of stands, data are included for trees that were similarly treated but not pruned; pruning costs were not assessed against these trees.

Table 4 shows that if 6% is taken as the lowest acceptable rate of return on actual investments, acceptable results usually required that the small-end diameters inside bark grow at annual rates of at least 0.25 inches and develop *radial* clear-shell thicknesses of at least 2.5 inches.

Table 4 also shows the peak rate of return that each tree earned on its own value during any 5-year period, with the value at the beginning of each period considered as the investment. In most cases, these returns still exceeded 6% when the experimental trees were harvested; for such trees, Table 4 shows the rate of compound interest that each tree earned on its own value during the last 5-year period. If the rate for each tree had fallen to 6% for some 5-year period, Table 4 shows the year in which the rate fell to 6% per annum. In the case of two unpruned trees in a slow-growing stand, this rate never reached 6%, a fact denoted by the entry "<6%."

Virtually all trees from the rapid-growth stand showed rates of interest return on both invested costs and growing stock that ranged from acceptable to very high. All trees were still earning rates of return on their own value high enough that an investor content with a 6% return would have left them to grow some more.

Trees with crowns that had been free to expand most of the time since the 1938 hurricane had all grown relatively large. The pruned ones showed good rates of return on invested costs even over as many as six decades, although the rates of return on value of growing stock had begun to fall below 6%. Since the stand had begun to close again, branches had also died on some upper logs. A more important problem with letting these trees grow so long was that the felling of their very large crowns caused excessive damage to small trees of the residual stand.

The only pruned trees from the thinned plantation with acceptable rates of return were those that had grown comparatively rapidly in diameter. While thinning around these particular trees had been heavy 23 years earlier, the treatments had not been repeated. All of the pruned trees were still yielding good rates of return on their value. It is possible that, if the stands were heavily thinned again, rates of return on invested costs might increase once more.

The only trees in the old, conventionally thinned stand that showed acceptable rates of return on invested costs were three that had grown faster than the majority of pruned trees in the stand. The best tree was the one with the most rapid diameter growth; the other two had live branches down to the pruning level. Most of the trees were still yielding good rates of return on their own value, but there seemed no possibility of recovering a good return on the sunk costs of pruning them. As with the plantation sample, failure to keep tree crowns free to expand often depressed the financial returns below the 6% level.

The data of Table 4 generally show that pruned trees with high proportions of stem length clothed with living branches were more valuable than those with many dead branches. Some of this is the result of the fact that such trees also grew faster and added clear wood more rapidly. Lumber from logs with red or tight knots is also more valuable than that from loose-knotted logs which have had dead branches for many years.

The results from comparable unpruned trees indicate that failure to invest in pruning was a choice almost sure to give poor results. The only ones that showed a 6% return on costs were two deep-crowned trees that had been released by the 1938 hurricane and had grown comparatively rapidly to large size.

Table 4. Data for individual trees ranked within stands by internal rate of return on invested costs.

Tree	IRR (1)	Grth Rate (2)	Total Val. $	Total Vol. (3)	Clear Shell (4)	Yrs (5)	Lengths (P-D-L) (6)	TH (7)	CPA (8)	DBH in.	RGS (9)
						Rapid-growth stand					
R1	19	63	81	76	3.1	10	12-0-8	53	486	12	95%
R2	16	42	74	332	2.8	13	16-0-24	71	1009	19	49%
R3	13	38	39	297	2.5	12	16-0-24	70	823	17	52%
R4	13	61	35	188	2.8	10	14-8-8	60	1370	18	90%
R5	13	36	61	229	2.6	20	16-0-25	67	727	16	36%
R6	12	40	63	232	3.4	15	16-0-30	68	1192	19	48%
R7	11	32	53	488	3.4	20	20-6-14	77	1346	22	30%
R8	10	29	56	362	3.2	20	16-16-16	82	625	18	22%
R9	10	42	57	570	2.9	15	14-0-52	100	605	20	18%
R10	10	34	52	406	3.2	18	16-14-16	79	949	20	39%
R11	10	33	58	294	3.2	20	16-24-8	76	553	16	12%
R12	10	32	37	467	3.0	18	24-0-34	98	920	21	17%
R13	5	26	11	224	2.2	15	24-0-12	77	920	17	33%
						Stand with heavy release in 1938 hurricane					
H1	11	32	201	805	4.7	30	16-22-20	94	1801	27	15%
H2	10	30	465	678	5.9	40	16-14-26	88	879	27	1985
H3	7	27	598	846	9.4	62	16-34-26	100	1604	27	1965
H4	6	22	110	512	4.8	43	16-16-30	92	568	19	1988
Unpruned trees from same stand:											
H5	6	23	71	475	0	--	0-42-18	83	1054	22	1970
H6	6	28	135	723	0	--	0-46-0	72	2818	25	1965
						Thinned plantation					
P1	12	31	148	386	3.3	23	16-16-10	77	975	20	10%
P2	7	25	50	270	2.9	23	16-0-26	78	507	16	16%
P3	7	31	33	301	3.6	23	12-0-24	72	691	17	31%
P4	6	23	31	148	2.8	23	20-0-20	70	449	15	7%
P5	5	21	22	205	2.3	23	18-12-8	72	389	14	21%
P6	4	28	20	178	2.6	23	18-10-10	67	480	14	7%
P7	3	23	13	175	2.2	23	16-14-0	73	339	14	11%

(continued)

Tree	IRR (1)	Grth Rate (2)	Total Val. $	Total Vol. (3)	Clear Shell (4)	Yrs (5)	Lengths P-D-L (6)	TH (7)	CPA (8)	DBH in.	RGS (9)
Unpruned trees from same stand:											
P8	5	32	15	275	0	--	0-28-14	77	500	16	21%
P9	3	23	5	183	0	--	0-18-26	75	340	13	12%
P10	2	25	4	165	0	--	0-14-26	73	260	13	1988
Old, conventionally thinned stand											
S1	8	23	100	434	3.7	35	16-16-12	91	1004	22	1985
S2	6	18	98	365	3.6	40	16-0-54	98	426	19	8%
S3	6	11	35	249	2.5	28	16-0-32	70	337	17	7%
S4	6	17	50	665	2.5	35	16-42-0	97	842	22	11%
S5	5	16	34	290	2.8	30	16-16-14	95	381	17	25%
S6	4	12	40	515	2.8	45	16-44-0	95	544	19	11%
S7	3	17	16	606	2.7	30	16-46-14	105	545	21	18%
S8	2	15	11	406	2.6	32	16-48-0	91	485	19	12%
S9	2	10	13	58	2.5	52	16-0-0	50	476	12	9%
S10	1	15	6	213	2.4	30	16-16-0	85	365	16	1964
S11	1	13	13	316	3.0	35	16-16-32	99	379	18	8%
Unpruned trees from same stand:											
S12	4	11	22	538	0	--	0-42-24	97	713	21	<6%
S13	3	17	12	345	0	--	0-32-40	90	403	17	14%
S14	3	11	12	446	0	--	0-50-10	93	792	20	1953

(1) IRR = internal rate of annual compound-interest return, %
(2) Annual rate of diameter growth, in hundredths of inches, at small end of first log since pruning date or for same period in case of unpruned trees
(3) Total volume recovered from tree, board feet, mill tally
(4) Radial thickness of clear shell, inches
(5) Number of years since pruning
(6) Merchantable length in feet subdivided into lengths of (P) pruned, (D) dead-knot, and (L) live-knot zones with half-foot trim allowances not included
(7) TH = total height, feet
(8) CPA = crown projection area = square feet of horizontal area covered by crown based on Eq. 1
(9) RGS = return on growing stock = annual compound-interest return on value of growing stock: in % for 1983-1988 if rate always >6%; if rate had fallen to 6%, the year in which it did; given as "<6%" if rate never attained 6%

Equally rapid growth in the unpruned plantation trees did not give acceptable returns. Investments in growing the unpruned trees did include the same charges for hardwood control, precommercial thinning, and area-related annual costs.

It should be noted that these estimates of rates of return are based not only upon the biological processes of growth of wood, but also upon lumber values that might change with demands of the market. High prices for clear or nearly clear Select grades as well as for wide widths have prevailed for many decades; the additional premiums being paid for thick boards may be temporary.

These results clearly demonstrate that very good returns on investments are possible if white pine is pruned early and thinned heavily enough that the tree crowns can expand unimpeded.

UNRESTRICTED GROWTH THINNING SCHEDULE FOR A MODEL TREE

Table 5 sets forth a program of treatment, based on Equation 1, for growing an "ideal" tree and for an acre of such trees.

This model tree was postulated as being 32 feet tall and 5.9 inches DBH when pruned to a height of 16 feet at which point the inside-bark diameter would be 3 inches. In the plantation stand of the study, such a tree would have been 25 years old, with living branches above 16 feet. At the time of pruning and every 5 years thereafter the thinning would be drastic enough that the crown would be free to expand horizontally. The rate of crown expansion used in the model is 1 foot of diameter annually, a rate slightly slower than the best observed in the study. The height growth rates of the model are taken from stem analysis data of the plantation stand, which had a 50-year site index of 68.

Dollar values were calculated in the same way as those for determining rates of return on tree value at 5-year intervals for actual trees. That is, conversion return on clear lumber depends mainly on thickness of clear shell, and knotty lumber is valued at $25 per thousand board feet.

The first part of Table 5 shows the results for growing such a tree for 30 years after pruning, regardless of how old it actually was at the time of pruning. A real rate of return of 13% on invested costs is sustained to the end of that period. The decline in rate of return on tree value and felling damage associated with trees having huge, green crowns suggest that this is near the time when the tree should be harvested.

To enable one to compare this model with regimes of light or no thinning, Table 5 also shows the per-acre

Table 5. Thinning schedule for ensuring unrestricted growth of pruned white pines with data both for individual tree and for one acre of them. Site index 68.

Per Tree

Age	Tot. Ht.	DBH	Clear Shell Thkns (a)	Bd.ft. Volume Clr (b)	Bd.ft. Volume Knt (c)	$/ Tree (d)	Ann. Int. on init. value (e)	Cmp. Int. on all costs (f)
25	32	5.9	0	-	-	0	--	0
30	41	8.6	1.2	-	-	0	--	0
35	49	11.2	2.6	20	12	13	Infinite	7%
40	54	14.0	4.0	66	37	58	35%	13%
45	62	16.6	5.2	111	82	122	16%	13%
50	68	19.2	7.0	172	151	245	15%	14%
55	75	21.9	7.8	233	241	370	9%	13%

(a) Radial thickness of shell of clear wood, inches
(b) Board feet of lumber of grade D Select & Better
(c) Board feet of knotty lumber of Common grades
(d) Tree value in terms of conversion return which is wholesale lumber value minus 110% of all costs of harvesting and processing
(e) Compound interest earned on initial value of tree by its growth during previous 5-year period
(f) Compound interest earned on investments in hardwood control, precommercial thinning, pruning, and annual costs of land ownership and forest management

Per Acre

Age	Tot. Ht.	Av. DBH	No. Trees Cut	Lv	Lv. BA (g)	Accum. $Harv. (h)	MAI $ (i)	MAI Bdft. (i)
25	32	5.9	many	76	25	0	0	0
30	41	8.6	0	76	30	0	0	0
35	49	11.2	24	52	36	$980	$29	72
40	54	14.0	14	38	41	3309	114	157
45	62	16.6	9	29	44	5772	131	217
50	68	19.2	6	23	46	9312	190	272
55	75	21.9	23	0	0	12186	226	311

(g) Basal area left after thinning
(h) Accumulated dollar value of all harvests in terms of conversion return
(i) Mean Annual Increment in dollars and board feet

results of growing an even-aged stand of ideal trees. In this case thinnings would be so heavy that they would become a form of shelterwood management. While it would be possible to grow such a stand it would be better to develop ones that had "ideal" trees scattered and isolated above one or two younger age-classes of trees from which "ideal" pruned trees would later be recruited. This more complicated arrangement, a variant of the true selection system, allows for controlling the white-pine weevil by partial shading.

If one tried to maintain an even-aged stand of such trees in canopy that kept closing, it would be difficult to avoid leaving large gaps in some spots and having tree crowns impinge on one another in other places. In the resulting uneven-aged stands the large amount of growing space left vacant by successive crown releases would be allocated to the development of younger age-classes destined for later treatment. This arrangement would create a situation in which fast-growing pruned trees bear most costs for the whole stand from the time they are pruned.

The hypothetical stand yield table of Table 5 shows that thinnings would be much heavier than those aimed at maximizing cubic or board-foot volume. This schedule is designed to optimize monetary returns. The results illustrate the general point that, in growing trees for lumber, monetary values can usually be optimized only by sacrificing some production of volume to increase stem diameter.

For the hypothetical yield table it is postulated that 76 trees per acre would have been pruned initially even though only 23 would be carried to the end of the 30-year period. Since the butt logs were of small diameter when pruned, they would have clear shells thick enough at the time of the first commercial thinning for the trees removed to yield significant dollar value.

Mean annual increments (MAI) of accumulated dollar value and board feet are shown for the hypothetical stand in Table 5. It is significant that MAI continues to rise at least to the 30th year after pruning. The MAI of 311 board feet per acre per year is about 40% lower than that of fully stocked unthinned stands (Leak et al., 1970), while the dollar MAI of $226 is far above the stumpage returns from extensive silviculture. This apparent loss of volume production is, however, partly compensated by the use of seemingly wasted growing space on the development of younger trees that may be tall enough to prune when the first crop is harvested.

Achieving such results requires conditions favorable to early pruning and timely thinnings. This is especially true if the candidate trees are so close together that they need frequent thinning. The high conversion returns can be turned into stumpage receipts only if the values of pruned pines are recognized on the market. This study shows that they exist.

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