Managing Lodgepole Pine to Yield Merchantable Thinning Products and Attain Sawtimber Rotations

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Introduction

Classical rotations in lodgepole pine (*Pinus contorta* var. *latifolia* Hopk.) are affected by the susceptibility of older, larger trees to attack by the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) (Cole and Amman 1969). A rotation is the time planned for commercial timber to grow before it is cut. For lodgepole pine, rotations much longer than 80 years increase the risk that mountain pine beetles will destroy or damage a significant proportion of the planned timber yield (Amman 1978; Cole 1989; Shore and Safranyik 1992). We define rotations of 80 years or less as physically attainable sawtimber rotations for lodgepole pine; the sawtimber has a high probability of being produced over the rotation.

Cole (1975) has shown the importance of stocking control and precommercial thinning for lodgepole pine. When such practices are used, stands can produce maximum yield of cubic volume per acre per year—within 80 years. The crop trees to be cut will average about 10 inches (25.4 cm) diameter at breast height (d.b.h.). Timber industry experience in both the United States and Canada has proven that such crop trees can provide valuable solid-wood products including house logs, small poles, sawed lumber, millwork, and veneer for plywood. Additionally, these small crop trees are suitable for:

- Flakes and strands used in reconstituted structural products such as flakeboard panels and lumber composites.
- Fiber products such as medium-density fiberboards, hardboards, and pulp for paper and packaging.

Managing lodgepole pine so it is ready to be cut as sawtimber in 80 years can cause a major problem. The early actions to reduce stocking increase stem taper in the remaining trees. The stand must be subsequently thinned, by about 30 years of age, if it is to be ready for commercial cutting at age 80. That becomes a problem when the stand is thinned with the intention of utilizing the trees cut during the thinning. Those trees may taper so quickly that they are not acceptable for natural roundwood products such as corral poles and fence rails.

Stocking control and thinning are expensive. The costs discourage managers from thinning lodgepole pine stands unless they can offset the costs by selling trees cut during the thinning (Koch and Barger 1988). It is important to find ways to sell these trees or offset the cost of recovering them so that lodgepole stands can be managed to reach commercial size before they are attacked by mountain pine beetles.

On commercial forest lands, many silviculturists, wildlife managers, and watershed managers would agree that the cost of juvenile stocking control should be paid by income from the previous harvest; it is part of the regeneration cost. The cost of precommercial thinning is the financial "bone in the throat" for forest managers. This paper suggests management and utilization regimes that allow products from a thinning at about age 30 to offset a significant proportion of the thinning costs.

Utilization of trees cut during thinning for manufactured roundwood products improves the economics of the thinning. The nature of these products and their markets has been explored in some depth by Jackson and Jackson (1989) and by Koch and others (1989). The characteristics of small lodgepole pine trees, including their physical, chemical, and mechanical properties, have been studied in considerable depth (Campbell and others 1990; Kim and others 1989; Koch 1987; Koch and Burke 1985; Koch and Schlieter 1991; Koch and others 1989; Koch and others 1990; Pellerin and others 1989; Wiedenbeck and others 1990).

The costs of selectively thinning lodgepole pine stands for small roundwood products have been reported by Benson (1987) and by Hawkins (1987b). Hawkins concluded that a few low-capital, labor-intensive, family operators could harvest these products economically; the better small contractors have organized crews, experienced and motivated workers, use their equipment efficiently, and can market their services.

nderlying Considerations

Koch (1987) has determined the average size of lgepole pine trees in unmanaged, natural lodgepole ne stands in North America. For stems delimbed to l-inch top, outside bark, the average size is:

D.b.h.	Length	Green weight
Inches	*Feet*	*Pounds*
3	26	45
4	35	120
5	42	190

managed stands that have received stocking control the juvenile stage, (less than about 16 years of age), ems of this diameter would be shorter and weigh mewhat less—because they would be younger and ave more taper. This suggests that thinnings can be and logged by small-scale operators with minimal quipment. The delimbed stems of trees cut during the inning could be taken to a processing plant. There, ey could be cut to product length and machined to a niform diameter. On large acreages, mechanical logging machines that cut, delimb, and segment stems to roduct lengths at the stump may be the best means of inning. Roundwood mill operators, however, would reatly prefer to receive stemwood in tree lengths, ather than in shorter segments.

Computer models have been prepared to account for efect and to maximize the value of roundwood products, by segmenting lodgepole pine trees cut during hinnings (Hawkins and Schlieter 1987; Schlieter and Hawkins 1989). The extent of defect from crook, fork, atface, knot cluster, canker swell, and sweep was letermined for a number of stands typical of nmanaged, small-stem, lodgepole pine stands in vestern Montana and northeastern Utah (Hawkins 1987a; Schlieter and Hawkins 1989). However, the Hawkins and Schlieter studies do not directly apply to stands that have received stocking control or precommercial thinning.

The products we will consider include machined fence rails, fence posts, and tree stakes. Because the stands will have undergone juvenile spacing (stocking control), the trees will have more limbs and taper when they are thinned at age 30 than is presently considered acceptable. For posts, this taper can be reduced in conventional debarkers. However, corral rails, fence rails, and tree stakes should have little taper. Doweling machines can remove all taper, producing very satisfactory 17-foot fence rails 2⅝ inches in diameter, and tree stakes as small as 2 inches in diameter. A well-maintained doweling machine can produce about 1,000 fence rails, or about 2,000 8-foot tree stakes, in 8 hours.

A tree can produce one debarked 6.5-foot-long fence post with a top diameter of 3.25 inches if the tree is at least 3.75 inches d.b.h., outside bark. When manufacturing posts, the finished product does not have to be perfectly round. For doweled rails, however, the eccentricity as well as the taper must be machined away by the doweling machine.

A long-term study of the effects of initial spacing on the future development of lodgepole pine is being conducted by Dennis Cole, this paper's senior author. Unpublished data from that study indicate that stem taper in managed lodgepole pine stands is appreciably greater than the taper in unmanaged stands reported by Hawkins and Schlieter (1987), Koch (1987), and Koch and others (1990). For managed stands, the minimum acceptable sizes of trees used for doweled products will have to be greater than for trees from unmanaged stands. We found trees needed to be at least 2.8 to 3.0 inches top diameter, inside bark, to produce 2⅝-inch-diameter doweled fence rails and tree stakes. Trees used to produce 2-inch diameter tree stakes had to be at least 2.1 inches top diameter, inside bark.

Our stem analysis data also revealed that site class and spacing level had significant effects on taper (p = 0.001) of the portion of the stem between 10 and 30 percent of tree height. Taper in this portion of tree stems is highly correlated with the minimum d.b.h. of trees suitable for products such as posts, stakes, and rails.

We found average taper was greatest (0.18 inches per foot) for the widest spacing in the lowest site class evaluated (12-foot spacing, site index 50). Average taper was least (0.08 inches per foot) for the narrowest spacing in the highest site class (6-foot spacing, site index 70). Site class and spacing combinations between these extremes had intermediate tapers. We used this information to define a range of minimum d.b.h., outside bark, for the different doweled products. The minimum d.b.h. ranges from the highest quality sites with the narrowest spacing to the lowest quality sites with the widest spacing:

Product	Length	Diameter	Minimum tree diameter: High site/ narrow	Minimum tree diameter: Low site/ wide
	Feet	*Inches*	--- *D.b.h.* ---	
Rails	17	2⅝	4.2	5.4
Stakes	8	2⅝	3.5	3.9
	8	2	2.8	3.2

Trees larger than the minimums might yield not only a 17-foot rail, but also a large-diameter fence post or an 8-foot tree stake. Operators would try to produce the products with the highest value, depending on a tree's size, taper, and any defects.

Crook and fork were the predominant defects at age 30 in Cole's unpublished initial spacing study. These defects were caused primarily by the terminal weevil (*Pissodes terminalis* Hopping), which destroyed terminal leaders. After age 30, little weevil infestation occurs and trees begin to outgrow the crook and fork defects (Amman and Safranyik 1985).

Our initial spacing study plots also show this pattern. Nonetheless, at age 30 these defects affect a tree's shape, reducing the likelihood it can become a doweled product. In the spacings most likely to be thinned, from 15 to 33 percent of the trees had defects that would prevent them from becoming 17-foot doweled fence rails. Because defects can influence product recovery from early thinnings, managers need to consider defects when evaluating the management opportunities for young lodgepole pine stands.

In March 1994, we found that untreated, debarked fence posts (that is bark-free posts with some taper) were in short supply. Their market values at the mill were about:

Top-end diameter	Value per post
Inches	*Dollars*
3 to 4	2.10
4 to 5	2.60
5 to 6	3.00-4.00

Untreated doweled fence rails, 17 feet long and about 3 inches in diameter at the small end, were in very short supply in April 1994. They were worth about $4 at the mill. Doweled tree stakes, 8 feet long and 2 inches in diameter, were worth about $1 at the mill.

Because trees thinned from managed stands have so much taper, the doweling machine will remove a large proportion of their volume when producing 17-foot fence rails. Few operators have markets for this waste, which poses some problems of disposal.

Operators will have to take waste into account when deciding the mix of roundwood products to manufacture from a given thinning. Many of the stems might best be utilized by debarking, selecting fence posts as available, then drying and doweling the remaining upper stem portions to various diameters suitable for roundwood furniture, porch railings, and pickets. Such value-added doweled products can utilize much shorter segments than required for 17-foot fence rails; the trees will lose less material when their taper is removed. In April 1994, products such as parts for roundwood furniture, porch railings, and pickets were worth more than 50 cents per lineal foot at the mill. Although we have not included estimates of the value of these products in this analysis, roundwood operators might be able to improve their returns by producing some of these shorter doweled products.

On public lands, regulations usually require that operators pay for stumpage or products before they are removed. This presents a cash-flow problem for the typical low-capital roundwood operator. This cash-flow problem, combined with the problem of taper in managed stands, usually makes it uneconomic to use young trees removed during prescribed thinning. It might be economic to use the trees if the operator were given a portion of the thinning stemwood in return for performing the prescribed thinning. The operator would benefit from the opportunity to make a profit offsetting his thinning and manufacturing costs, while the landowner would be able to institute a chosen management regime. Removing a major portion of the thinning stemwood would significantly reduce fire hazard for much of the 50 years remaining in the rotation—substantially increasing the probability the stand will reach its planned rotation. All limbs and tops would be left on site to return nutrients to the soil. If prescribed thinnings were carried out as we have proposed, land management agencies could reduce costs for:

- Prescribed thinning
- Wildfire suppression
- Contract preparation and administration.

Purpose and Objectives

In light of the aforementioned background on thinning and roundwood products, we will present management regimes for attainable lodgepole pine rotations, considering:

- The timing and intensity of juvenile spacing (stocking control).
- The size of thinned stems.
- The number of machined fence rails, fence posts, and tree stakes available.
- The yield characteristics of the stands at rotation.

These management regimes not only provide attainable rotations, but allow forest managers to offset thinning costs in exchange for thinning residues able to provide raw material for high-value roundwood products—while addressing other resource concerns such as wildlife cover and forage. This information should help those developing cost-benefit data for planned thinnings, and ultimately those seeking economic ways to improve management and utilization of the many resources of lodgepole pine forests.

Procedure

A revised version of the lodgepole pine subroutine LPPIM (Cole and Edminster 1985) of the stand growth model RMYLD (Edminster 1978) was used to simulate growth and yield effects in managed stands. The LPPIM subroutine was revised to scale the basal area increment equation, for the tree of average stand diameter, to data from Cole's unpublished long-term study of early spacing in lodgepole pine. The original equation was developed from variable-density data from unmanaged, and predominantly older, lodgepole pine stands (Cole and Stage 1972). The original equation underestimated growth of young, managed lodgepole pine stands. Until we had data on the response of lodgepole pine trees to thinning, we couldn't refine the equation. Using the new data, we compared the predicted basal area increments (of the tree of average stand diameter) with values measured in thinned stands of site index classes 50, 60, and 70 feet at 100 years. The predicted values averaged 79 percent of the observed values. We scaled the basal area increment equation upward by using the reciprocal of the ratio of predicted to observed values (1.27) as a multiplier. After this modification, the subroutine produced values of average stand diameter and average dominant height that were close to the observed values in thinned stands of different spacings measured at 20, 30, and 40 years of age.

Stand projections were made with the revised LPPIM subroutine, producing growth and yield tables for different management regimes. Projections were begun at 20, 30, and 40 years of age. The simulated thinnings were of a range of stand densities assumed to have been created by stocking control at age 10. To account for site quality effects, a separate series of projections was made for 100-year site index (Alexander 1966) classes of 50, 60, and 70 feet.

We determined the starting values of average stand diameter and dominant height in the projections from comparable stand density levels of the lodgepole pine spacing study. Many different stocking-control and thinning prescriptions were evaluated to find those that would produce an average stand diameter (root mean square diameter) of about 10 inches (25.4 cm) by 80 years of age. Some thinnings at age 20 allowed the target rotation to be reached, but trees were too small then to be used for doweled fence rails; therefore, thinning at age 20 received no further consideration. However, with stocking control at 10 years and thinning at 30 years, we found a number of merchantable thinning prescriptions that would provide an attainable 80-year rotation.

Thinning Patterns

Not all thinning prescriptions can be accomplished on the ground, even though they are indicated by growth and yield models or projections. For example, a stand uniformly stocked with 1,210 trees per acre (6-foot spacing) cannot be thinned to 436 reasonably well-spaced trees per acre (10-foot spacing).

We chose two simple thinning patterns as being attainable in practice (fig. 1). Pattern A , a square spacing pattern, increases the average tree spacing by multiples of the average spacing before thinning. For example, a stand with average spacing of 6 feet can be

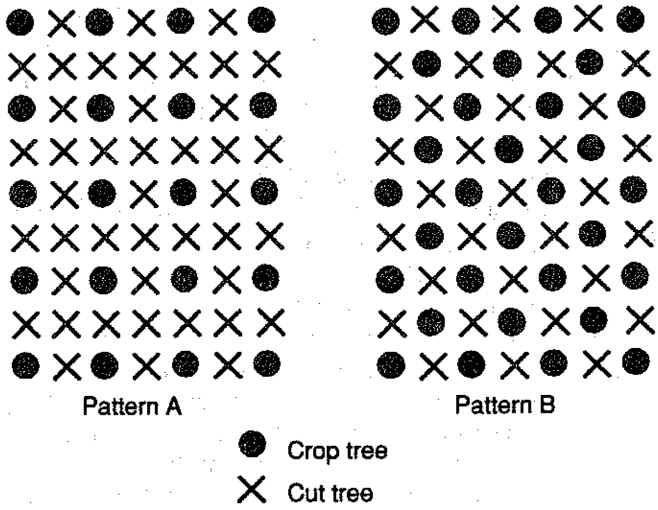

Figure 1—Practical thinning patterns for naturally regenerated lodgepole pine stands.

thinned with pattern A to 12 or 18 feet average spacing. Thinning to twice the existing spacing reduces the number of trees by 75 percent; thinning to three times the existing spacing reduces the number of trees by 89 percent.

Pattern B is essentially a diagonal spacing pattern, most often used in thinning stands previously spaced to pattern A. Every other tree in the existing rows is removed according to the pattern shown in figure 1. Pattern B increases spacing by about 141 percent, while reducing the number of trees by 50 percent.

Determining Taper and Merchantable Thinning Products

Our first approach was to use Kozak's (1988) taper equation for lodgepole pine to estimate the minimum d.b.h. and stem length to minimum top diameter for the doweled products. This model seriously underestimated the taper in our juvenile-spaced stands. This was probably due to abnormal taper our trees developed from repeated loss of terminal leaders to terminal weevils. Because we had too few sample trees for the very complex form of Kozak's model, we were unable to refit his model to our managed-stand data. Therefore, we took another approach.

We conducted a stem analysis on 108 felled trees obtained in the fall of 1993 from our spacing study plots. We analyzed 12 trees each from the 6-, 9-, and 12-foot spacings in each of the three site classes. The stem analysis trees were cut from the buffer areas surrounding the central subject-tree areas of the spacing plots. We chose this area to have the least effect on the future growth of spacing study subject trees while still getting trees representative of the spacing.

Each 12-tree sample was selected to represent the distribution of breast height diameters occurring in each spacing plot. Felled trees were cut at a stump height of 0.5 foot, and measured for total height above the stump. Felled stems were marked at breast height (4.0 feet above the stump cut) and at 10, 30, 50, 70, and 90 percent of height above the stump. Stem wafers were cut from each of these marked locations, as well as from the stump. The wafers were labeled and placed in sealed plastic bags.

In the laboratory, outside-bark and inside-bark diameters were measured on the wafers taken at breast height. Inside-bark diameters were measured on all other wafers. Measurements were recorded as the average of two right angle diameters, located and marked on each wafer such that their intersection was near the center of the wafer.

Average inside-bark diameters were determined at 10, 30, 50, 70, and 90 percent of the height above the stump. We used interpolation to determine the fraction of total cut stem length to the point where inside bark diameter was 3.0 inches. That fraction was multiplied by the total height above the stump to obtain the merchantable stem length at the time of our analysis.

Because the average stand age was greater than 30 years, the merchantable lengths had to be scaled downward to represent their length at 30 years of age. We did so by multiplying the length by a ratio determined for each plot from the spacing study remeasurement data. This ratio was the average total tree height of plot subject trees at 30 years of age divided by the average total height of the same trees at the time of our analysis. The estimated merchantable stem lengths at 30 years of age were then evaluated for the different machined products they could provide.

Two utilization alternatives were evaluated—fence posts only (alternative 1) and doweled fence rails and fence posts together (alternative 2). In the case of 6.5-foot fence posts, the number of available posts per tree ranged from one to four, depending on the utilization alternative and the site class and spacing. A weighted overall ratio of number of fence posts per tree was determined for each site class-spacing combination. It was the sum of the weighted proportions of each sample that yielded one, two, three, and four posts.

For example, in a given spacing and site class, the proportion of the trees yielding four 6.5-foot posts was multiplied by 4, the proportion yielding three posts was multiplied by 3, and so on. The sum of these weighted proportions for fence posts could be (and often was) greater than 1.

When 17-foot doweled fence rails were the preferred utilization alternative (alternative 2), some trees provided only a 17-foot fence rail, some provided a rail and a fence post, and others yielded only a fence post or two.

In both utilization alternatives, an 8-foot long, 2-inch diameter, doweled tree stake could be produced from all trees less than 3.8 inches d.b.h., outside bark, based on our stem analysis data.

The product ratio for tree stakes was 1.0 per tree for trees less than 3.8 inches d.b.h. Because the ratio was the same for both utilization alternatives, we did not compute weighted proportions for tree stakes. The product ratio per tree was simply the proportion of stem analysis trees that provided one product piece.

Stem defects varied between the different spacing study locations and influenced the usable length of thinning stems that exceeded minimum diameters. We accounted for these effects on the overall product ratio per tree (the yield) of each product, for each site class and spacing level in our stem analysis data. Since we had no replicate plots to determine "typical" levels of defect for the different site classes, we treated the 12-tree sample of stem analysis trees from each site class and spacing combination as representative of "observed" defect. To obtain an idea of product availability when trees had few defects, we determined the average height/d.b.h. ratio of the top 25 percent of stem analysis trees for each site class and spacing combination. We reasoned that these trees had the largest height-to-diameter ratios because any defects had less effect (particularly less frequent damage or loss of terminal leaders) than other trees in the sample. These trees provided a subsample for determining a merchantable height/d.b.h. ratio. That ratio could be used as a multiplier with tree d.b.h. at 30 years of age to estimate the merchantable heights stem analysis trees would probably attain if they had few defects.

The differences in product ratios per tree between the "observed" and the "low" defect situations are not definitive for these site classes and spacings. We believe they do show the relative importance of stem defects on the numbers of recoverable products from thinnings. They also show the importance of surveying stands for stem defects before determining the number of products that can be recovered from thinnings.

The cumulative percentage distributions of d.b.h. were computed from long-term remeasurement data for 6-, 9-, and 12-foot spacings. These distributions were used as reference distributions for the simulated thinnings that produced the target sawtimber rotation. The reference distributions were used to determine the percentage of stems larger than 3.8 inches d.b.h. (outside bark) at the time of thinning. This is the minimum size that can be used for fence posts and doweled fence rails. The percentage of trees smaller than 3.8 inches d.b.h. was determined to calculate the number of 8-foot long, 2-inch diameter doweled tree stakes available from trees too small for fence posts or fence rails.

These stand percentages were multiplied by the ratios determined from the stem analysis samples to obtain product multipliers for each site class-spacing combination (table 1). Multipliers for spacings between the 6-, 9-, and 12-foot spacings were determined by linear interpolation; those for spacings of 12.5 and 12.75 feet were determined by extrapolation.

Finally, the number of thinning stems per acre were multiplied by the product multipliers of table 1. The result was the number of the different products expected per acre for the different management regimes and utilization alternatives.

Results and Discussion

Management regimes that provide attainable rotations were summarized by three site index classes and several initial stand density classes to indicate:

- Ages, spacings, and patterns of thinnings.
- Yield of thinning products under a fence-post-only utilization alternative (alternative 1) and a fence rail and fence post alternative (alternative 2).
- Growth and yield statistics at and near the assumed rotation age of 80 years (tables 2 through 4).

The results summarized in tables 2 through 4, and the conclusions drawn from them, are heavily dependent on projections. Users should compare the summary results presented here with local growth and utilization data, making adjustments as necessary.

The numbers of fence posts, doweled fence rails, and doweled tree stakes available from thinning vary widely among the alternative management regimes. Timber yields at the target rotation vary significantly only with site class.

The data in tables 2 through 4 support a number of generalizations:

- For a given juvenile spacing, development of average tree d.b.h. to age 30 is inversely correlated with the initial (regeneration) density of the stand.
- Regardless of the density before juvenile spacing, thinning yields (at age 30) are highest with about 7 x 7-foot juvenile spacing for sites with 100-year indexes of 50 and 60 feet, and with 6 x 6-foot juvenile spacing for a site index of 70 feet. With such juvenile spacings, a number of different thinnings at age 30 will produce crop trees of at least 10 inches d.b.h., by age 80.
- When stands with the recommended juvenile spacings are thinned at age 30, the trees cut during the

Table 1—Product multipliers for 30-year-old lodgepole pine stands spaced at 10 years of age to three spacing levels, by site index class and defect level.

Site index class[1]	Defect level[2]	Spacing	Product multipliers: 8.0-ft tree stakes[3]	6.5-ft fence posts only[4]	Fence rails and fence posts: 17-ft rails[5]	Fence rails and fence posts: 6.5-ft posts[4]
		Feet				
50	Observed	6 x 6	0.67	0.33	0.00	0.33
		9 x 9	0.41	0.47	0.00	0.47
		12 x 12	0.18	1.06	0.00	1.06
	Low	6 x 6	0.67	0.66	0.00	0.66
		9 x 9	0.41	1.06	0.00	1.06
		12 x 12	0.18	1.90	0.25	1.15
60	Observed	6 x 6	0.33	0.64	0.00	0.64
		9 x 9	0.10	1.53	0.00	1.53
		12 x 12	0.00	1.45	0.09	1.27
	Low	6 x 6	0.33	0.82	0.09	0.64
		9 x 9	0.10	1.84	0.28	1.28
		12 x 12	0.00	1.89	0.36	1.17
90	Observed	6 x 6	0.28	1.20	0.12	0.96
		9 x 9	0.26	1.48	0.20	1.08
		12 x 12	0.16	1.61	0.38	0.83
	Low	6 x 6	0.28	1.68	0.72	0.12
		9 x 9	0.26	1.96	0.74	0.13
		12 x 12	0.16	2.52	0.76	0.46

[1]Lodgepole pine site index at 100 years, in feet (Alexander 1966).
[2]Defect level: Observed = the defect level for all trees in stem analyses samples.
Low = the defect level for the 25 percent of stem analysis trees having the highest height/d.b.h. ratio.
[3]Finished diameter = 2.0 inches.
[4]Minimum finished top diameter = 3¼ inches.
[5]Minimum finished top diameter = 2⅝ inches.

Table 2—Management regimes for attainable rotations in lodgepole pine, for stands with a site index of 50 feet at 100 years.

Initial stocking	Initial spacing	Stand at 10 years after stocking control: Spacing in ft (pattern)[1]	Stand at 10 years after stocking control: Tpa[2]	Stand at 30 years, Before thinning: Average diameter	Before thinning: Dominant height[3]	After thinning: Crop tree stocking	After thinning: Spacing (pattern)[1]	Number of thinning products per acre, Alternative 1, 6.5-ft fence posts[4]: Obs.[9] defect	Alternative 1, 6.5-ft fence posts[4]: Low[10] defect	Alternative 2, 17-ft doweled fence rails[5]: Obs. defect	Alternative 2, 17-ft doweled fence rails[5]: Low defect	Alternative 2, 6.5-ft fence posts[4]: Obs. defect	Alternative 2, 6.5-ft fence posts[4]: Low defect	Alternatives 1 and 2: 8.0-ft doweled tree stakes[6]	Stand averages at 80 years: Diameter[7]	Stand averages at 80 years: Dominant height[3]	Approximate age when average diameter ≥10 inches	Total volume at 80 years	Merchantable volume at 80 years[8]
Tpa	*Feet*			*Inches*	*Feet*	*Tpa*									*Inches*	*Feet*	*Years*	- - - Ft^3/*Acre*	- -
>14,000	<1.76	7.00 (A)	890	3.4	23	222	14.00 (A)	254	(528)	0	(0)	254	(528)	448	10.1	43	78	2,270	2,143
		8.80 (A)	562	4.3	23	283	12.40 (B)	128	(287)	0	(0)	128	(287)	117	9.6	43	87	2,300	2,162
		10.50 (A)	395	4.7	23	198	14.80 (B)	146	(292)	0	(0)	146	(242)	57	10.4	43	76	2,200	2,045
10,000-	1.75-	8.00 (A)	680	4.1	24	170	16.00 (A)	214	(469)	0	(0)	214	(469)	250	11.2	44	64	2,200	2,090
14,000	2.00	10.00 (A)	436	4.7	24	219	14.10 (B)	141	(254)	0	(0)	141	(254)	72	10.1	44	78	2,230	2,105
		10.50 (A)	395	4.8	24	198	14.80 (B)	128	(292)	0	(0)	128	(230)	57	10.7	44	74	2,180	2,067
		12.00 (A)	300	5.2	24	150	17.00 (B)	159	(285)	0	(38)	159	(173)	27	11.6	44	60	2,070	1,969
6,970-	2.10-	8.40 (A)	617	4.3	24	154	16.80 (A)	204	(454)	0	(0)	204	(454)	213	11.4	45	63	2,100	1,997
10,000	2.50	10.00 (A)	436	4.8	24	219	14.10 (B)	141	(291)	0	(0)	141	(237)	72	10.2	45	77	2,250	2,126
		10.50 (A)	395	5.0	24	198	14.80 (B)	128	(292)	0	(0)	146	(217)	57	10.8	45	68	2,260	2,144
		12.00 (A)	300	5.3	24	150	17.00 (B)	159	(285)	0	(38)	159	(173)	27	11.7	44	59	2,090	1,988
		12.50 (A)	279	5.4	24	139	17.70 (B)	165	(286)	0	(42)	165	(162)	20	12.0	44	56	2,060	1,961
5,760	2.75	8.25 (A)	640	4.4	24	160	16.50 (A)	206	(451)	0	(0)	206	(451)	226	11.6	45	60	2,220	2,111
		11.00 (A)	360	5.1	24	180	15.60 (B)	148	(292)	0	(29)	148	(230)	45	11.1	45	64	2,210	2,100
		13.75 (A)	230	5.7	24	230	13.75 (nt)	0	(0)	0	(0)	0	(0)	0	10.3	44	75	2,300	2,176
4,840	3.00	9.00 (A)	538	4.5	24	268	12.70 (B)	127	(286)	0	(0)	127	(286)	111	9.7	45	86	2,280	2,145
		12.00 (A)	300	5.4	24	150	17.00 (B)	159	(285)	0	(38)	159	(173)	27	11.8	44	57	2,100	1,999
4,124	3.25	9.75 (A)	458	4.8	24	229	13.80 (B)	137	(261)	0	(0)	137	(247)	80	10.2	45	78	2,300	2,174
3,556	3.50	7.00 (A)	890	4.0	24	222	14.00 (A)	267	(548)	0	(0)	267	(548)	428	10.2	45	77	2,280	2,155
		10.50 (A)	395	5.0	24	198	14.80 (B)	128	(292)	0	(0)	146	(218)	57	10.8	45	68	2,260	2,144
3,098	3.75	7.50 (A)	775	4.0	24	194	15.00 (A)	232	(500)	0	(0)	232	(500)	308	10.7	45	70	2,250	2,133
		11.25 (A)	344	5.2	24	172	15.90 (B)	151	(291)	0	(31)	151	(194)	40	11.4	44	62	2,220	2,028
2,722	4.00	8.00 (A)	680	4.2	24	170	16.00 (A)	214	(469)	0	(0)	214	(469)	250	11.3	44	63	2,220	2,111
		12.00 (A)	300	5.4	24	150	17.00 (B)	159	(285)	0	(38)	159	(173)	27	11.8	44	57	2,100	1,997
		12.00 (A)	300	5.4	24	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	9.5	44	90	2,440	2,291
2,412	4.25	8.50 (A)	600	4.4	24	150	17.00 (A)	203	(446)	0	(0)	203	(446)	203	11.8	45	57	2,130	2,026
		12.75 (A)	268	5.6	24	134	18.00 (B)	166	(283)	0	(44)	166	(155)	17	12.3	45	53	2,080	1,982
		12.75 (A)	268	5.6	24	268	12.75 (nt)	0	(0)	0	(0)	0	(0)	0	9.8	44	83	2,370	2,233
2,150	4.50	9.00 (A)	538	4.6	24	268	12.70 (B)	127	(286)	0	(0)	127	(286)	111	9.8	45	85	2,300	2,167
		13.50 (A)	239	5.7	24	239	13.50 (nt)	0	(0)	0	(0)	0	(0)	0	10.3	44	75	2,350	2,223
1,931	4.75	9.50 (A)	483	4.7	24	242	13.40 (B)	135	(289)	0	(0)	135	(258)	89	10.0	45	80	2,340	2,209
		14.25 (A)	215	5.9	24	215	14.25 (nt)	0	(0)	0	(0)	0	(0)	0	10.5	44	72	2,240	2,121
1,742	5.00	10.00 (A)	436	4.9	24	219	14.10 (B)	141	(291)	0	(0)	141	(237)	72	10.3	45	75	2,270	2,147
1,580	5.25	10.50 (A)	395	5.0	24	198	14.80 (B)	146	(292)	0	(0)	146	(218)	57	10.8	45	68	2,260	2,144
1,440	5.50	11.00 (A)	360	5.1	24	180	15.60 (B)	148	(292)	0	(29)	148	(230)	45	11.1	45	64	2,210	2,100
1,210	6.00	12.00 (A)	300	5.5	24	150	17.00 (B)	159	(285)	0	(38)	159	(173)	27	11.9	45	56	2,140	2,037
890	7.00	7.00 (A)	890	4.2	24	222	14.00 (A)	267	(574)	0	(0)	267	(574)	387	10.4	45	74	2,310	2,185

[1]Leave tree spacing pattern as shown in figure 1, nt = no thinning.
[2]Tpa = trees per acre.
[3]Average height of dominant trees.
[4]Minimum top diameter of finished fence post is 3.25 inches, inside bark.
[5]Diameter after doweling is 2⅝ inches.
[6]Diameter after doweling is 2 inches. Defects do not affect the number available.
[7]Average stand diameter in inches, by basal area.
[8]Volume per acre in trees larger than 4½ inches d.b.h. to a top diameter, inside bark, of 3.0 inches.
[9]Products available under observed defect conditions.
[10]Products available under low defect represented by the upper 25th percentile of trees, according to height/d.b.h. ratio.

Table 3—Management regimes for attainable rotations in lodgepole pine, for stands with a site index of 60 feet at 100 years.

Initial stocking	Initial spacing	Stand at 10 years after stocking control: Spacing in ft (pattern)[1]	Stand at 10 years after stocking control: Tpa[2]	Stand at 30 years: Before thinning: Average diameter	Stand at 30 years: Before thinning: Dominant height[3]	Stand at 30 years: After thinning: Crop tree stocking	Stand at 30 years: After thinning: Spacing (pattern)[1]	Number of thinning products per acre: Alternative 1: 6.5-ft fence posts[4]: Obs.[9] defect	Alternative 1: 6.5-ft fence posts[4]: Low[10] defect	Alternative 2: 17-ft doweled fence rails[5]: Obs. defect	Alternative 2: 17-ft doweled fence rails[5]: Low defect	Alternative 2: 6.5-ft fence posts[4]: Obs. defect	Alternative 2: 6.5-ft fence posts[4]: Low defect	Alternatives 1 and 2: 8.0-ft doweled tree stakes[6]	Stand averages at 80 years: Diameter[7]	Stand averages at 80 years: Dominant height[3]	Approximate age when average diameter ≥10 inches	Total volume at 80 years	Merchantable volume at 80 years[8]
Tpa	*Feet*			*Inches*	*Feet*	*Tpa*									*Inches*	*Feet*	*Years*	- - - *Ft*^{3}*/Acre*	- -
>14,000	<1.76	7.00 (A)	890	3.8	26	222	14.00 (A)	621	(768)	0	(100)	621	(568)	220	11.0	52	66	3,340	3,173
		8.80 (A)	562	4.6	26	283	12.40 (B)	413	(492)	0	(73)	413	(346)	31	9.9	52	81	3,400	3,206
		10.50 (A)	395	5.1	27	198	14.80 (B)	294	(362)	8	(61)	278	(240)	10	11.4	52	63	3,150	2,996
		12.30 (A)	288	5.5	27	288	12.30 (nt)	0	(0)	0	(0)	0	(0)	0	10.1	52	79	3,470	3,279
10,000-	1.75-	8.00 (A)	680	4.5	27	170	16.00 (A)	622	(755)	0	(107)	622	(541)	87	12.0	53	56	3,070	2,923
14,000	2.00	10.00 (A)	436	5.1	27	219	14.10 (B)	329	(399)	7	(65)	315	(269)	13	11.0	53	67	3,260	3,097
		10.50 (A)	395	5.2	27	198	14.80 (B)	296	(362)	9	(61)	278	(240)	10	11.5	53	61	3,170	3,015
		12.00 (A)	300	5.6	27	150	17.00 (B)	219	(284)	14	(54)	191	(176)	0	12.6	53	53	2,900	2,764
		12.00 (A)	300	5.6	27	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.0	52	80	3,500	3,304
6,970-	2.10-	8.40 (A)	617	4.7	27	154	16.80 (A)	620	(744)	0	(106)	620	(532)	65	12.5	53	52	2,980	2,839
10,000	2.50	10.00 (A)	436	5.2	27	219	14.10 (B)	329	(399)	7	(65)	315	(269)	13	11.1	53	65	3,280	3,116
		10.50 (A)	395	5.4	27	198	14.80 (B)	294	(362)	8	(61)	278	(240)	10	11.7	53	58	3,210	3,053
		12.00 (A)	300	5.7	27	150	17.00 (B)	219	(284)	14	(54)	191	(176)	0	12.7	53	51	2,930	2,792
		12.00 (A)	300	5.7	27	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.1	52	78	3,520	3,323
		12.50 (A)	279	5.8	27	139	17.70 (B)	202	(267)	15	(53)	172	(161)	0	13.2	53	48	2,930	2,795
5,760	2.75	8.25 (A)	640	4.8	27	160	16.50 (A)	619	(750)	0	(106)	619	(538)	72	12.5	53	50	3,060	2,916
		11.00 (A)	360	5.5	27	180	15.60 (B)	267	(336)	11	(60)	245	(216)	5	12.1	53	54	3,130	2,980
		13.75 (A)	230	6.1	27	230	13.75 (nt)	0	(0)	0	(0)	0	(0)	0	11.0	52	65	3,230	3,069
4,840	3.00	9.00 (A)	538	4.9	27	268	12.70 (B)	413	(498)	0	(76)	413	(346)	27	10.4	53	75	3,440	3,254
		12.00 (A)	300	5.8	27	150	17.00 (B)	219	(284)	14	(54)	191	(176)	0	12.8	53	49	2,950	2,811
		12.00 (A)	300	5.8	27	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.2	52	77	3,540	3,345
4,124	3.25	9.75 (A)	458	5.2	27	229	13.80 (B)	347	(421)	5	(66)	337	(289)	16	11.0	53	64	3,290	3,126
3,556	3.50	7.00 (A)	890	4.4	27	222	14.00 (A)	715	(915)	0	(127)	715	(661)	180	11.2	53	63	3,370	3,202
		10.50 (A)	395	5.4	27	198	14.80 (B)	294	(362)	8	(61)	278	(240)	10	11.7	53	58	3,210	3,053
3,098	3.75	7.50 (A)	775	4.5	27	194	15.00 (A)	633	(808)	0	(105)	633	(598)	122	11.7	53	58	3,230	3,072
		11.25 (A)	344	5.6	27	172	15.90 (B)	254	(321)	12	(58)	230	(205)	3	12.2	53	53	3,100	2,951
2,722	4.00	8.00 (A)	680	4.6	27	170	16.00 (A)	622	(755)	0	(107)	622	(541)	87	12.1	53	54	3,090	2,942
		12.00 (A)	300	5.8	27	150	17.00 (B)	219	(284)	14	(54)	191	(176)	0	12.8	53	49	2,950	2,811
		12.00 (A)	300	5.8	27	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.2	52	77	3,540	3,345
2,412	4.25	8.50 (A)	600	4.8	27	300	12.00 (B)	411	(495)	0	(72)	411	(351)	39	10.1	53	78	3,580	3,380
		8.50 (A)	600	4.8	27	150	17.00 (A)	617	(743)	0	(108)	617	(527)	59	12.8	53	51	3,030	2,888
		12.75 (A)	268	6.0	27	268	12.75 (nt)	0	(0)	0	(0)	0	(0)	0	10.6	52	70	3,450	3,267
2,150	4.50	9.00 (A)	538	5.0	27	268	12.70 (B)	413	(498)	0	(76)	413	(346)	27	10.5	53	73	3,460	3,277
		13.50 (A)	239	6.1	27	239	13.50 (nt)	0	(0)	0	(0)	0	(0)	0	11.0	52	64	3,330	3,164
1,931	4.75	9.50 (A)	483	5.1	27	242	13.40 (B)	363	(446)	2	(70)	359	(306)	19	10.8	53	67	3,360	3,188
		14.25 (A)	215	6.3	27	215	14.25 (nt)	0	(0)	0	(0)	0	(0)	0	11.4	52	60	3,260	3,100
1,742	5.00	10.00 (A)	436	5.3	27	219	14.10 (B)	329	(399)	7	(65)	315	(269)	13	11.2	53	63	3,300	3,135
1,580	5.25	10.50 (A)	395	5.4	27	198	14.80 (B)	296	(362)	9	(61)	278	(240)	10	11.7	53	58	3,210	3,053
1,440	5.50	11.00 (A)	360	5.5	27	180	15.60 (B)	267	(336)	11	(60)	245	(216)	5	12.1	53	54	3,130	2,980
1,210	6.00	6.00 (nt)	1210	4.4	27	300	12.00 (A)	974	(1247)	0	(173)	974	(901)	246	10.1	53	78	3,630	3,427
		12.00 (A)	300	5.9	27	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.3	52	76	2,970	2,810
		12.00 (A)	300	5.9	27	150	17.00 (B)	219	(284)	14	(54)	191	(176)	0	12.9	53	48	3,560	3,393
890	7.00	7.00 (A)	890	4.6	27	222	14.00 (A)	815	(988)	0	(140)	815	(708)	167	11.4	53	60	3,510	3,338

[1] Leave tree spacing pattern as shown in figure 1, nt = no thinning.
[2] Tpa = trees per acre.
[3] Average height of dominant trees.
[4] Minimum top diameter of finished fence post is 3.25 inches, inside bark.
[5] Diameter after doweling is 2⅝ inches.
[6] Diameter after doweling is 2 inches. Defects do not affect the number available.
[7] Average stand diameter in inches, by basal area.
[8] Volume per acre in trees larger than 4½ inches d.b.h. to a top diameter, inside bark, of 3.0 inches.
[9] Products available under observed defect conditions.
[10] Products available under low defect represented by the upper 25th percentile of trees, according to height/d.b.h. ratio.

Table 4—Management regimes for attainable rotations in lodgepole pine, for stands with a site index of 70 feet at 100 years.

		Stand at 30 years																	
								Number of thinning products per acre											
		Stand at 10 years after stocking control		Before thinning		After thinning		Alternative 1		Alternative 2				Alternatives 1 and 2	Stand averages at 80 years				
Initial stocking	Initial spacing	Spacing in ft (pattern)[1]	Tpa[2]	Average diameter	Dominant height[3]	Crop tree stocking	Spacing (pattern)[1]	6.5-ft fence posts[4]		17-ft doweled fence rails[5]		6.5-ft fence posts[4]		8.0-ft doweled tree stakes[6]	Diameter[7]	Dominant height[3]	Approximate age when average diameter ≥10 inches	Total volume at 80 years	Merchantable volume at 80 years[8]
								Obs.[9] defect	Low[10] defect	Obs. defect	Low defect	Obs. defect	Low defect						
Tpa	Feet			Inches	Feet	Tpa									Inches	Feet	Years	- - - Ft[3]/Acre - -	
>14,000	<1.76	7.00 (A)	890	4.2	29	222	14.00 (A)	801	(1122)	80	(481)	641	(80)	187	11.8	60	57	4,200	3,998
		8.80 (A)	562	5.0	29	283	12.40 (B)	335	(494)	53	(201)	299	(33)	73	10.8	60	70	4,380	4,157
		10.50 (A)	395	5.5	29	198	14.80 (B)	303	(439)	57	(148)	187	(57)	41	12.1	60	56	4,080	3,884
		10.50 (A)	395	5.5	29	395	10.50 (nt)	0	(0)	0	(0)	0	(0)	0	9.7	60	85	4,680	4,404
		12.30 (A)	288	5.9	29	288	12.30 (nt)	0	(0)	0	(0)	0	(0)	0	10.8	60	71	4,400	4,175
10,000-14,000	1.75-2.00	8.00 (A)	680	4.9	30	170	16.00 (A)	704	(949)	82	(372)	530	(61)	138	13.0	61	51	3,940	3,755
		10.00 (A)	436	5.5	30	219	14.10 (B)	330	(464)	56	(163)	215	(52)	48	11.9	61	59	4,190	3,989
		10.50 (A)	395	5.6	30	198	14.80 (B)	303	(439)	57	(148)	187	(57)	41	12.2	61	54	4,080	3,884
		10.50 (A)	395	5.6	30	395	10.50 (nt)	0	(0)	0	(0)	0	(0)	0	9.8	61	82	4,720	4,446
		12.00 (A)	300	6.1	30	150	17.00 (B)	242	(378)	57	(114)	125	(69)	24	13.6	61	48	3,750	3,574
		12.00 (A)	300	6.1	30	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.7	60	70	4,410	4,181
6,970-10,000	2.10-2.50	8.40 (A)	617	5.1	30	154	16.80 (A)	648	(875)	83	(343)	486	(56)	125	13.5	61	47	3,840	3,660
		10.00 (A)	436	5.6	30	219	14.10 (B)	330	(464)	56	(163)	215	(52)	48	12.0	61	56	4,200	3,998
		10.50 (A)	395	5.8	30	198	14.80 (B)	303	(439)	57	(148)	187	(57)	41	12.4	61	51	4,110	3,913
		10.50 (A)	395	5.8	30	395	10.50 (nt)	0	(0)	0	(0)	0	(0)	0	10.0	61	80	4,780	4,512
		12.00 (A)	300	6.2	30	150	17.00 (B)	242	(378)	57	(114)	125	(69)	24	13.7	61	46	3,770	3,593
		12.00 (A)	300	6.2	30	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.8	61	68	4,430	4,204
		12.50 (A)	279	6.3	30	279	12.50 (nt)	0	(0)	0	(0)	0	(0)	0	11.1	61	64	4,400	4,180
5,760	2.75	8.25 (A)	640	5.2	30	160	16.50 (A)	672	(902)	82	(350)	504	(58)	130	13.5	61	45	3,940	3,755
		11.00 (A)	360	6.0	30	180	15.60 (B)	281	(419)	58	(137)	164	(63)	34	12.9	61	49	4,060	3,869
		11.00 (A)	360	6.0	30	360	11.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.4	61	73	4,740	4,484
		13.75 (A)	230	6.6	31	230	13.75 (nt)	0	(0)	0	(0)	0	(0)	0	12.0	61	55	4,230	4,027
4,840	3.00	6.00 (A)	1210	4.3	30	300	12.00 (A)	1092	(1529)	109	(655)	874	(109)	253	10.7	62	70	4,590	4,351
		9.00 (A)	538	5.3	30	268	12.70 (B)	400	(529)	54	(200)	292	(35)	70	11.2	61	64	4,400	4,180
		12.00 (A)	300	6.3	30	150	17.00 (B)	242	(378)	57	(114)	125	(69)	24	13.8	61	44	3,790	3,612
		12.00 (A)	300	6.3	30	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.9	60	66	4,450	4,228
4,124	3.25	9.75 (A)	458	5.6	30	229	13.80 (B)	346	(479)	57	(169)	231	(48)	53	11.9	61	58	4,220	4,017
3,556	3.50	7.00 (A)	890	4.8	30	222	14.00 (A)	875	(1209)	94	(481)	695	(80)	180	12.0	62	55	4,280	4,075
		10.50 (A)	395	5.8	30	198	14.80 (B)	303	(439)	57	(148)	187	(57)	41	12.4	61	51	4,110	3,913
3,098	3.75	7.50 (A)	775	4.8	30	194	15.00 (A)	784	(1051)	87	(424)	598	(70)	157	12.5	62	51	4,100	3,903
		11.25 (A)	344	6.1	30	172	15.90 (B)	270	(409)	58	(131)	153	(62)	31	13.2	61	46	3,930	3,745
		11.25 (A)	344	6.1	30	344	11.25 (nt)	0	(0)	0	(0)	0	(0)	0	10.5	61	76	4,650	4,404
2,722	4.00	8.00 (A)	680	5.0	30	170	16.00 (A)	704	(949)	82	(372)	530	(61)	138	13.1	61	49	3,950	3,764
		12.00 (A)	300	6.3	30	150	17.00 (B)	242	(378)	57	(114)	125	(69)	24	13.8	61	44	3,790	3,612
		12.00 (A)	300	6.3	30	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.9	60	66	4,450	4,228
2,412	4.25	8.50 (A)	600	5.2	30	300	12.00 (B)	426	(573)	54	(222)	318	(36)	81	10.9	61	68	4,540	4,313
		8.50 (A)	600	5.2	30	150	17.00 (A)	639	(860)	81	(333)	477	(54)	122	13.7	61	44	3,860	3,679
		12.75 (A)	268	6.4	31	268	12.75 (nt)	0	(0)	0	(0)	0	(0)	0	11.4	61	60	4,480	4,260
2,150	4.50	9.00 (A)	538	5.4	30	268	12.70 (B)	400	(529)	54	(200)	292	(35)	70	11.3	61	62	4,400	4,180
		13.50 (A)	239	6.5	31	239	13.50 (nt)	0	(0)	0	(0)	0	(0)	0	11.8	61	57	4,330	4,118
1,931	4.75	9.50 (A)	483	5.5	30	242	13.40 (B)	361	(494)	55	(178)	248	(43)	0	11.7	61	58	4,360	4,146
		14.25 (A)	215	6.7	31	215	14.25 (nt)	0	(0)	0	(0)	0	(0)	0	12.2	61	53	4,120	3,922
1,742	5.00	10.00 (A)	436	5.7	30	436	10.00 (nt)	0	(0)	0	(0)	0	(0)	0	9.7	60	86	4,880	4,592
		10.00 (A)	436	5.7	30	219	14.10 (B)	330	(464)	56	(163)	215	(52)	48	12.1	61	54	4,210	4,008

(con.)

Table 4—(Con.)

Initial stocking	Initial spacing	Stand at 10 years after stocking control: Spacing in ft (pattern)[1]	Stand at 10 years after stocking control: Tpa[2]	Stand at 30 years: Before thinning: Average diameter	Before thinning: Dominant height[3]	After thinning: Crop tree stocking	After thinning: Spacing (pattern)[1]	Number of thinning products per acre: Alternative 1: 6.5-ft fence posts[4]: Obs.[9] defect	Alternative 1: 6.5-ft fence posts[4]: Low[10] defect	Alternative 2: 17-ft doweled fence rails[5]: Obs. defect	Alternative 2: 17-ft doweled fence rails[5]: Low defect	Alternative 2: 6.5-ft fence posts[4]: Obs. defect	Alternative 2: 6.5-ft fence posts[4]: Low defect	Alternatives 1 and 2: 8.0-ft doweled tree stakes[6]	Stand averages at 80 years: Diameter[7]	Stand averages at 80 years: Dominant height[3]	Approximate age when average diameter ≥10 inches	Total volume at 80 years	Merchantable volume at 80 years[8]
Tpa	*Feet*			*Inches*	*Feet*	*Tpa*									*Inches*	*Feet*	*Years*	- - - *Ft³/Acre* - -	
1,580	5.25	10.50 (A)	395	5.8	30	198	14.80 (B)	303	(439)	57	(148)	187	(57)	41	12.4	61	51	4,110	3,913
		10.50 (A)	395	5.8	30	395	10.50 (nt)	0	(0)	0	(0)	0	(0)	0	10.0	60	80	4,780	4,512
1,440	5.50	11.00 (A)	360	6.2	30	180	15.60 (B)	281	(419)	58	(137)	164	(63)	34	13.1	61	46	4,100	3,907
		11.00 (A)	360	6.2	30	360	11.00 (nt)	0	(0)	0	(0)	0	(0)	0	10.6	60	70	4,760	4,508
1,210	6.00	6.00 (nt)	1210	4.6	30	300	12.00 (A)	1174	(1611)	118	(655)	910	(109)	246	10.9	62	67	4,630	4,399
		12.00 (A)	300	6.5	30	300	12.00 (nt)	0	(0)	0	(0)	0	(0)	0	11.1	61	63	4,470	4,247
		12.00 (A)	300	6.5	30	150	17.00 (B)	242	(378)	57	(114)	125	(69)	24	14.0	61	41	3,840	3,663
890	7.00	7.00 (A)	890	5.0	30	222	14.00 (A)	915	(1255)	94	(488)	701	(80)	180	12.3	62	51	4,300	4,094

[1]Leave tree spacing pattern as shown in figure 1, nt = no thinning.
[2]Tpa = trees per acre.
[3]Average height of dominant trees.
[4]Minimum top diameter of finished fence post is 3.25 inches, inside bark.
[5]Diameter after doweling is 2⅝ inches.
[6]Diameter after doweling is 2 inches. Defects do not affect the number available.
[7]Average stand diameter in inches, by basal area.
[8]Volume per acre in trees larger than 4½ inches d.b.h. to a top diameter, inside bark, of 3.0 inches.
[9]Products available under observed defect conditions.
[10]Products available under low defect represented by the upper 25th percentile of trees, according to height/d.b.h. ratio.

thinning will have the characteristics described in table 5.

- In stands with the level of defects that we observed, the number of roundwood products per acre from thinnings at age 30 are described in table 6.
- If the stands have significantly fewer defects ("low" defect in tables 2 through 4), product yields will be significantly higher.
- When thinned at age 30 to the densities specified below, the stands will yield crop trees with an average stand diameter of 10 inches in less than 80 years, as described in table 7.
- If the thinned stands are carried to rotation at age 80, the characteristics of the stands are described in table 8.

Management Implications

The initial stocking of young lodgepole pine stands ranges widely. Target rotations often cannot be achieved unless the initial stocking and site index are carefully considered when determining the appropriate levels and patterns of stocking control and thinnings.

Stocking control (juvenile spacing) is important for each site class, but it is especially important for site class 50 stands, particularly dense stands with spacings less than 2.75 feet (table 2). For site class 50 stands, the only management regimes that reach the target rotation are those with thinning at age 30. Even the densest stands on site class 60 and above have one or more stocking control spacings that will not require thinning to reach the target rotation (tables 3 and 4).

Juvenile spacings that do not require later thinning are economically attractive. But stands with such low densities promote early development and extended retention of excess limbwood, and excess taper of stems (Koch and Schlieter 1991). If thinnings can provide meaningful economic returns, using them might be better than using stocking control spacings that do not require later thinning.

Two other problems with stocking control involve initial stand density and the stand age when stocking is controlled. These are the problems of fill-in regeneration (ingress) when stocking control spacing is too wide and the problem of regrowth from live limbs that are left on stumps (Cole 1993). Managers and planners should consider these problems when choosing management regimes presented in tables 2 through 4.

Cole (1993) showed that regeneration ingress in lodgepole pine stands is positively correlated with tree spacing after stocking control, and with the cross product of spacing and the years elapsed since stocking control. He concluded that ingress capable of compromising stocking goals would probably only occur when trees were spaced to greater than about 10 feet, before the stand was 16 years old. The management regimes summarized in tables 2 through 4 assume stocking control when the stand is 10 years old. Ingress could be a problem for some of these regimes—unless the trees are removed before they become a problem. However, for all the initial spacing classes presented in tables 2 through 4—except spacings of 5.25 to 6.0 feet in site class 50 (table 2)—some regimes allow stocking control spacings to be 10 feet or less.

Trees removed during stocking control thinnings may regrow from limbs left on their stumps. In some regions, only stands with more than 15,000 to 20,000 trees per acre should have stocking controlled before they are 12 years old. Only stands with more than 10,000 to 15,000 trees per acre should have stocking controlled before about 16 years of age. For each of these guidelines, the lower level in the stocking range applies to lower site classes and the higher level applies to higher site classes. These guidelines assure

Table 5—Characteristics of trees thinned at age 30 after juvenile spacing.

Juvenile spacing	Site index	Average d.b.h.	Height of dominants	Stem volume to apical tip
Feet	*Feet*	*Inches*	*Feet*	*Cubic feet/tree*
7 x 7	50	3.4 to 4.2	23 to 24	0.77 to 1.20
7 x 7	60	3.8 to 4.6	26 to 27	1.08 to 1.61
6 x 6	70	4.3 to 4.6	29 to 30	1.53 to 1.80

Table 6—Roundwood products per acre from thinnings at age 30.

Juvenile spacing	Site index	Stems cut	Product yields: Posts	Product yields: Tree stakes	Product yields: Rails
Feet	*Feet*	*No./acre*	*No./acre*		
7 x 7	50	668	254 to 267	387 to 488	
7 x 7	60	668	621 to 815	167 to 220	
6 x 6	70	910	1,092 to 1,174	246 to 253	
				or	
			874 to 910	246 to 253	109 to 118

Table 7—Characteristics of crop trees for stands with an average d.b.h. of 10 inches, for stands thinned at age 30.

Site index	Stand after thinning		Characteristics of crop trees at 10 inches average d.b.h.			
	Density	Spacing	Age	Height	Number	Volume
Feet	*Trees/acre*	*Feet*	*Years*	*Feet*	*Trees/acre*	*Ft³/tree*
50	222	14	74 to 78	42 to 44	186	11.24 to 11.81
60	222	14	60 to 66	45 to 46	208	12.09 to 12.37
70	300	12	69 to 70	57	267	15.49

Table 8—Characteristics of thinned stands at the rotation age of 80 years.

Site index	Crop trees	Average d.b.h.	Height of dominants	Total stemwood volume
Feet	*No./acre*	*Inches*	*Feet*	*Ft³/acre*
50	186	10.2 to 10.4	43 to 45	2,280 to 2,310
60	196	11.2 to 11.4	52 to 53	3,370 to 3,510
70	251	10.7 to 10.9	60 to 61	4,590 to 4,630

that the lowest live limbs will not be below a 0.5-foot stump (Cole 1993).

The management regimes in tables 2 through 4 assume that stocking is controlled at 10 years. If stocking were not controlled before 16 years, fewer management regimes would allow stands to reach 10 inches average stand diameter by 80 years of age. The third column from the right of tables 2 through 4 shows the approximate ages when stands managed under the different regimes reach 10 inches average stand diameter. If stocking control were delayed for 6 years in stands with more than 10,000 trees per acre, the stand would not reach 10 inches average stand diameter for more than another 6 years. When stocking control is delayed 6 years, we have assumed an 8-year delay for management regimes to reach the target rotation. Management regimes that take 73 years or more to reach the target rotation in tables 2 through 4 probably would not reach the target rotation in 80 years if stocking control were delayed for 6 years.

Delaying stocking control until stands are 16 years old causes the greatest concern for site class 50, where about 29 percent of the management regimes would fail to reach the target rotation. For site class 60, only 19 percent of the management regimes would not reach the target rotation if stocking were delayed; for site class 70, only 12 percent of the management regimes would not reach the target rotation.

Managers have two ways to deal with the possibility that branches left on stumps might regrow after stocking control thinnings:

- They can control stocking when the stand is 10 years old and clean the stand of any regrowth that develops.
- They can wait until the stand is 16 years old before controlling stocking, using only management regimes that will reach 10 inches average stand diameter by the target rotation.

Conclusions

This paper can be used for evaluating a number of resource considerations. For example, tables 2 through 4 can be used with lodgepole pine canopy development models (Cole 1983; Cole and Jensen 1982). In addition, values in the tables can be used in models of:

- Snow interception, snow melt, and water yield and quality (Leaf 1975; Meiman 1987; Swanson 1985, 1987).
- Hiding and thermal cover relationships for wildlife (Thomas and others 1979).
- Vegetation occurrence and development (Basile 1975; Dealy 1975; Urness 1985).

The alternatives presented in tables 2 through 4 provide managers flexibility in attaining the target rotation of 80 years in lodgepole pine stands. Since managers have flexibility, especially in the stands that are densest, they can choose tree spacings to favor other important factors such as understory vegetation, wildlife habitat and cover, and water yield and quality.

More specific cost-benefit data may be developed for the various management regimes presented here. If so, managers will be able to make even better decisions, choosing the most cost-effective regimes from among those that attain the target rotation while providing other specific multiple resource goals.

Managing lodgepole pine forests on a landscape scale will require managers to give greater emphasis to diversity in stand size, site quality, and age class—and to the juxtaposition of these stands on the landscape. In this context, managers might identify opportunities to ensure dispersed thermal and hiding cover for big game. Fewer juvenile-spaced lodgepole pine stands of lower site quality (for instance, a site index of less than 60 feet at 100 years) might be thinned so the unthinned stands could provide thermal and hiding cover. On the other hand, juvenile lodgepole pine stands occupying better sites could be managed for the most economic return, in a pattern that would enhance forest diversity and multiple resource goals while providing attainable rotations.

Even if lodgepole pine stands were treated to achieve the target sawtimber rotation of 80 years, they could be harvested before or after the normal rotation to increase biological diversity across the landscape. An earlier harvest would not fully realize the expected sawtimber yields. If the rotation were extended, the probability of mountain pine beetle attack and wildfire would steadily increase. Across the landscape a proportion of stands could be planned for extended rotations, even rotations beyond 150 years. But the increased loss from insects and fire would have to be considered acceptable and the loss deemed manageable in the overall context of ecosystem management. If a large-scale wildfire occurred before the planned rotations for stands in the area, the rotation goals of all stands in the area would probably need to be reconsidered.

One way to reduce the mountain pine beetle risk for extended rotations would be to commercially thin selected stands when they are 80 years old and again when their crowns close or when the growth of crop trees declines markedly. Although these commercial thinnings may be uneconomic or may decrease overall timber yields, they might be prescribed to achieve extended rotations for landscape-scale management. Such thinnings would emulate the characteristics of mature stands that experienced understory fires, such as those that historically occurred in some lodgepole pine habitat types. The safest way to achieve extended lodgepole pine rotations would be to manage stands under the regimes presented in summary tables 2 through 4, while maintaining the option of extending the rotation of preselected stands.

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