USDA United States Department of Agriculture

Forest Service

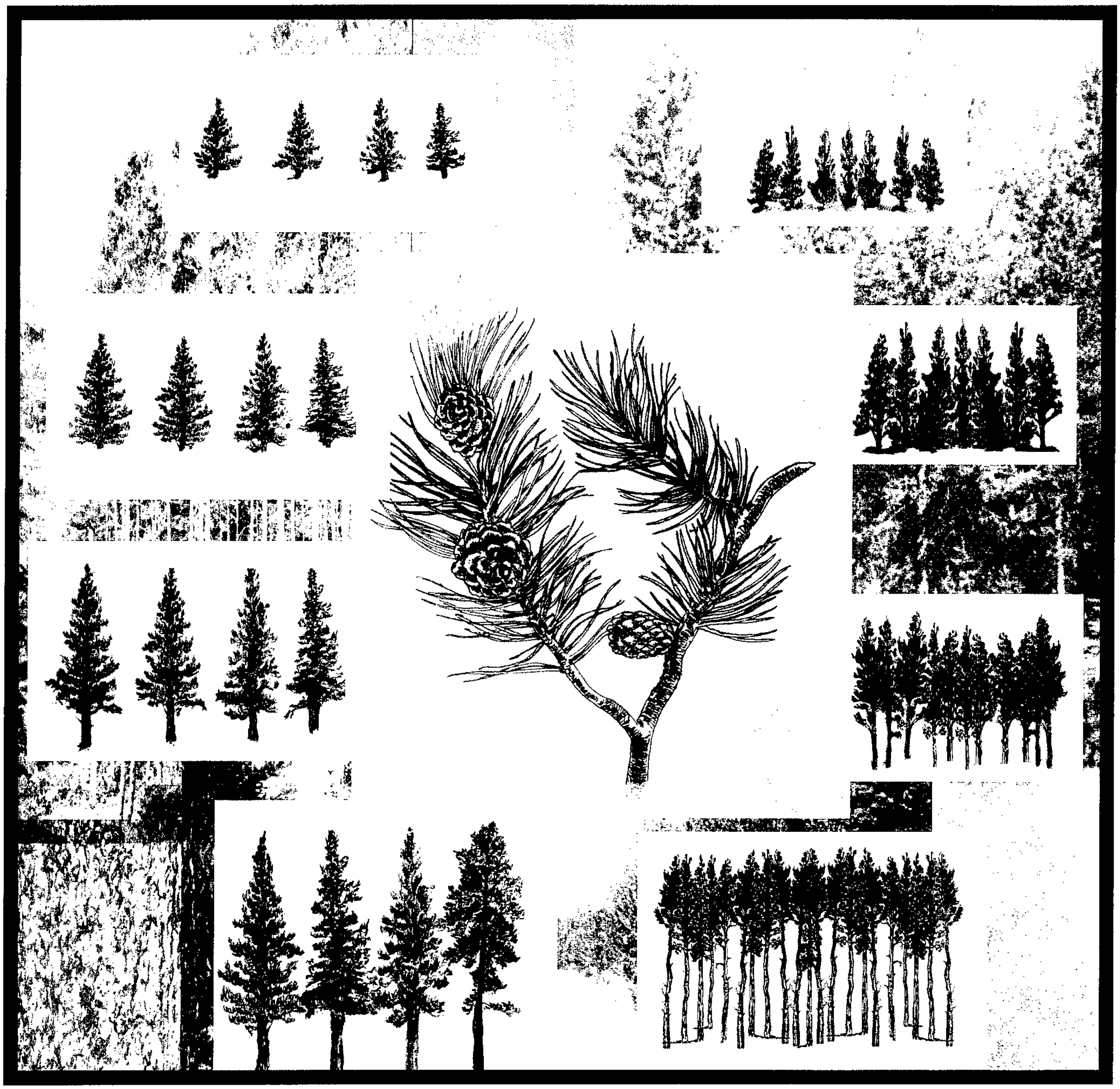
Pacific Northwest Research Station

Research Paper PNW-RP-503 February 1998

Lodgepole Pine Development After Early Spacing in the Blue Mountains of Oregon

P.H. Cochran and Walter G. Dahms

PB98-136310



Authors

P.H. COCHRAN is a consultant in forest resources, University of Idaho, Moscow, ID 83843. He was principal research soil scientist (retired); and WALTER G. DAHMS was a research forester (retired), at the now-closed Silviculture Laboratory, Bend, OR.

Abstract

Cochran, P.H.; Dahms, Walter G. 1998. Lodgepole pine development after early spacing in the Blue Mountains of Oregon. Res. Pap. PNW-RP-503. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

Seedlings were thinned to spacings of 6, 9, 12, 15, and 18 feet and measured periodically. Twenty-seven years after treatment, quadratic mean diameters increased curvilinearly ($p \leq 0.05$) as spacing increased, but total height did not differ significantly ($p \leq 0.05$) with spacing. Corresponding basal areas decreased curvilinearly ($p \leq 0.05$), and cubic volumes decreased linearly ($p \leq 0.05$) as spacing increased. All periodic annual increments differed with period or age. Periodic annual increments for mean diameter and basal area varied curvilinearly ($p \leq 0.05$), whereas volume increments varied linearly ($p \leq 0.05$) with spacing for each period. Height increments were greatest at intermediate spacings during some periods, at wide spacings during other periods, and at the narrowest spacing during one period. Crown widths increased ($p \leq 0.05$) as spacing widened. Fifty percent crown cover was attained at a stand density index of about 80 for all spacings. Simulation to a breast high age of 100 years indicated that the most merchantable cubic volume was produced at the 6-foot spacing but that the 12-, 15-, and 18-foot spacings produced about the same board-foot volume.

Keywords: Growth, lodgepole pine, Blue Mountains (Oregon), thinning, simulation.

Summary

Dense natural regeneration was thinned to spacings of 6, 9, 12, 15, and 18 feet 4 years after establishment, and tree and stand development was followed for 27 years. Only 1.9 percent of the trees died during the study. At the end of the study, quadratic mean diameters (QMDs) increased curvilinearly ($p \leq 0.05$) as spacing increased, but total height did not differ significantly ($p \leq 0.05$) with spacing. Corresponding basal areas decreased curvilinearly ($p \leq 0.05$), and cubic volumes decreased linearly ($p \leq 0.05$) as spacing increased. An 18-foot spacing contains 134 trees per acre. Volumes of the 134 trees per acre with the largest diameters increased curvilinearly with increasing spacing, thereby indicating that the presence of smaller trees influences the growth of the larger trees in the stand. All periodic annual increments (PAIs) differed with period or age. The PAIs for QMD and basal area varied curvilinearly ($p \leq 0.05$), whereas volume PAIs varied linearly ($p \leq 0.05$) with spacing for each period. Height PAIs were greatest at intermediate spacings during some periods, at wide spacings during other periods, and at the narrowest spacing during one period. Crown widths increased ($p \leq 0.05$) curvilinearly as spacing widened. Fifty percent crown cover was attained at a stand density index (SDI) of 80; 70 percent crown cover was attained at an SDI of 120. Some wildlife biologists believe stands with 50 to 70 percent crown cover are necessary for thermal cover. At SDIs above 170, lodgepole pine (*Pinus contorta* Dougl. ex Loud.) stands with some 9-inch diameter trees are susceptible to heavy mortality from mountain pine beetles (*Dendroctonus ponderosae* Hopkins). Fifty to seventy percent crown cover may be impossible to attain in older stands at SDIs below 170. Early spacing control to allow development of wide crowns will be necessary to approach 50 percent crown cover at SDIs below 170. Simulation to a breast high age of 100 years indicated the most merchantable cubic volume was produced at the 6-foot spacing but that the 12-, 15-, and 18-foot spacings produced about the same board-foot volume.

Introduction

Initial spacing and ensuing stand density regimes for lodgepole pine (*Pinus contorta* Dougl. ex Loud.) substantially affect future tree sizes and wood production. Johnstone (1985) reviewed available lodgepole pine thinning results and reached the following conclusions: (1) Response to thinning is directly related to the degree of thinning. (2) Absolute growth response seems to be greatest on high sites, but the greatest relative response occurs on low sites. (3) Response to thinning is inversely related to age. (4) Growth response within stands seems to increase with increasing initial tree size, thereby indicating that thinning should be from below. Crown characteristics (Cole 1983, Johnstone and Pollack 1990), understory production and composition (Basile 1975, Dealy 1975), hiding and thermal cover (Cole 1983, Smith and Long 1987), mortality (Barrett 1961; Mitchell and others 1983, 1991; Peterson and Hibbs 1989), and the overall appearance of future landscapes also can vary greatly with differing density management practices. Although the influence of spacing on the development of coniferous plantations generally is understood, little quantitative information is available to prescribe plantation management regimes for lodgepole pine (Johnstone and Pollack 1990). More information about lodgepole pine stand development in response to early spacing, therefore, is important.

The 27-year responses of growth, mortality, and crown cover to five spacings imposed on a natural lodgepole pine stand 4 years after establishment are reported here. Results from simulating the development of these spacings to a breast high age of 100 years also are presented. The soil and plant community are typical of many high-elevation lodgepole pine sites in the Blue Mountains of northeastern Oregon and southeastern Washington. The results should be applicable for many other areas in the West with similar soils, climate, and vegetation.

Methods of Study

Study Area

The study area is 22 miles south 10 degrees west of La Grande, Oregon, in section 27 of T. 6 S., R. 37 E., Willamette Meridian, at an elevation of 5,800 feet. Aspect is west 6 degrees north, and the slope is 9 percent. Subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.), western larch (*Larix occidentalis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and lodgepole pine are present nearby. Grouse huckleberry (*Vaccinium scoparium* Leiberg) is the prominent understory ground cover. The soil consists of a 10-inch ash layer with a 1.5-inch A1 horizon overlaying a silt loam to clay loam older soil with 50-percent fractured rock. The site index for lodgepole pine (Dahms 1975) averages 87 feet at a total age of 100 years. Site index values range from 60 to 110 feet east of the Cascade Range in Oregon and Washington.

Stand History and Study Establishment

The area is within the 19,500-acre Anthony burn which occurred in 1960. Large numbers of new seedlings came up in spring 1961, with lodgepole pine being the dominant species in the new stand.

The completely randomized experiment consists of five spacings, 6, 9, 12, 15, and 18 feet, replicated twice for a total of 10 rectangular plots. Plot area increased with spacing from 0.215 acres for the 6-foot spacing to 0.327, 0.377, 0.506, and 0.729 acres for the 9-, 12-, 15-, and 18-foot spacings, respectively. The plots do not have buffer strips and are bounded on one or two sides by plots of different spacings and on the remaining sides by the natural stand spaced from 9 to 12 feet. Interior plots containing two to three rows with a total of 24 trees in the center of each plot were originally designated to be measured. These interior rows of sample trees are surrounded by two to four rows of trees with the same spacing. Interior plot areas containing these 24 trees are 0.020, 0.045, 0.079, 0.124, and 0.178 acre for the 6-, 9-, 12-, 15-, and 18-foot spacings, respectively.

The study was installed in summer 1965. The desired spacings were established by marking trees to be saved and pulling up the excess trees. In a few instances, mainly at the 6-foot spacing, trees did not exist at the desired location. In this situation, a nearby tree was dug up and planted at the proper place. All trees in the study plots are lodgepole pine.

Measurements and Analyses

Height measurements of all trees were taken in fall 1965 and 1970. Height (H) and diameter at breast height (d.b.h.) of all trees were measured in fall of each of the following years: 1971, 1974, 1976, 1979, 1982, 1987, and 1992. Diameter measurements outside bark at 1.0-, 4.5-, 10- and then at 5-foot intervals up the stem also were taken for the 24 interior plot trees (or survivors) on the 1971-92 dates. Diameters inside bark were estimated from bark-thickness equations developed from other studies. Cubic volume inside bark (V), including stump and tip for each of these trees, was determined by using diameters inside bark with Smalian's formula. These data were used to create a volume equation (Schumacher and Hall 1933) with unique coefficients for each plot-date combination,

$$\log_e V = a + b[(\log_e(\text{d.b.h.})] + c(\log_e H) .$$

Coefficients for each plot-date combination were determined by using linear regression analyses.

Crown widths of the 24 interior plot trees or their survivors also were determined at each measurement. Crown cover was calculated assuming circular crown shapes. When crown widths were wider than spacing, crown cover was obtained by subtracting the area not covered by crown from spacing squared.

Stand density index (SDI) was calculated for each plot at each measurement by using,

$$SDI = TPA(QMD/10)^b ,$$

where TPA is trees per acre, QMD is quadratic mean diameter, and b equals 1.74. A value of 1.74 instead of the traditional value of 1.605 was used for b because a least squares fit of $\log_e$(TPA) versus $\log_e$(QMD) for the normally stocked plots used by Dahms (1975) for development of gross yields of lodgepole pine in south-central Oregon resulted in a slope value of -1.74.

Average annual mortality rates (MR) for each plot for the 27-year period were determined as negative interest rates by using (Hamilton and Edwards 1976),

$$MR = 1 - (N2/N1)^{(1/n)} ,$$

where N1 is the number of live trees at the start of the measurement period, N2 is the number of live trees at the end of period, and n is the number of years (27) in the measurement period.

Periodic annual increments (PAI, growth during each period divided by the number of growing seasons in the period) were calculated for gross and net basal area and volume. The PAIs of QMD, and average height also were determined for surviving trees.

The 1992 volume of a fixed number of trees with the largest diameters for each spacing was determined as a percentage of the total fall 1992 volume on the narrowest spacing. These percentages indicate the reduction in growth of the large trees because of the competition from smaller trees.

Two sets of SDI values, mortality, and growth data for each plot were determined. One set was obtained by using only the interior plots (24 sample trees or their survivors), and the other set was obtained by using all trees on the plot.

Split-plot analyses of variance, standard analyses of variance, or repeated measures (split-plot in time) analyses of variance (SAS Institute 1988) were used to test the following hypotheses: (1) The QMD, average height, average volume per tree, and trees per acre did not differ with spacing or location of trees within the plot (the interior plot trees versus all other plot trees) 27 years after treatment. (2) Mortality did not differ with spacing. (3) The PAIs were the same for all spacings and periods. (4) Volume of the 134 trees per acre with the largest diameters on each spacing did not differ with spacing, thereby indicating that the smaller trees had no effect on the growth of the larger trees. (5) Crown widths and crown cover did not differ with treatment or period. Linear, quadratic, and lack of fit effects for the response variables versus spacing were tested in both the standard and repeated measures analyses by using orthogonal polynomial methods. In the repeated measures analyses, these effects also were tested for the period by spacing interaction. Intervals between measurements ranged from 1 to 5 years for heights and 2 to 5 years for diameters.

The PAIs for QMD, volume, and basal area also were plotted as a function of period mean SDI to picture the relation of these PAIs to a density measure other than spacing. The period mean SDI is the average of the SDI values determined from live trees at the start and end of each period.

Stand Projections

Treatments were projected forward from fall 1992 (breast high age of 24 years) to a breast high age of 100 years to aid in the assessment of the various spacings by using equations from a revised version of LPSIM.[1] A breast high age limit of 100 years was used because lodgepole pine in this area seems to rapidly lose vigor past this age. Scribner board-foot volumes to a 5-inch top for trees 6.9 inches and larger and merchantable cubic-foot volumes for all trees to a 3-inch top were estimated. Mortality rates were assumed to be zero for these simulations. Thinnings were simulated when SDIs exceeded 170 if 9-inch trees were present to reduce the probability of serious damage from mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (Cochran and others 1994, Mitchell and others 1983, Peterson and Hibbs 1989). Plots with 9-inch trees were thinned back to an SDI of 112. Plots without 9-inch trees were not thinned until an SDI of 208 was exceeded and then were thinned back to an SDI of 139. An SDI of 208 is 75 percent of 277, the SDI considered equivalent to normal stand densities for lodgepole pine in central Oregon (Cochran and others

[1] The height growth and volume increment equations of LPSIM (Dahms 1983) have been revised by using additional data from young stands not available in 1983.

1994). Maintaining stand densities below 75 percent of normal should nearly eliminate suppression-related mortality. Trees from all size classes were removed in these simulated thinnings so that mean tree size before and after the simulated thinnings were the same. Maintaining the same tree size was accomplished computationally in the simulation by increasing the plot size to obtain the desired SDI. Two sets of simulations were run; one set for all whole-plot trees and another for only the interior plot trees.

Scribner board-foot and cunit values for each thinning and for the volume at breast high age 100 were discounted back to the time of establishment by using an interest rate of 4 percent to compare possible differences in values resulting from the different spacings. Board-foot and cunit values used were derived from prices paid for recent sales of live lodgepole pine on the Deschutes National Forest. Scribner board-foot value (V_{bf}) for QMDs greater than 11 inches was $210 per thousand. The board-foot value in dollars per thousand for smaller QMDs was,

$$V_{bf} = 26(\text{QMD}) - 76 .$$

A value of $80 per cunit was used for merchantable volumes greater than 1,400 cubic feet per acre. A cunit value (V_c) of,

$$V_c = 4.615(\text{number of cunits}) + 15.39 ,$$

was used for merchantable cubic-foot volumes less than 1,400 cubic feet per acre. Log values can be influenced by the number and size of branches, stem taper, amount of sapwood, and wood density (Ballard and Long 1988). None of these factors were considered in determining board-foot or cunit values for the simulation results.

Results

Tree Sizes in 1992 Within and Outside Interior Plots

The difference between QMD on the interior plot and QMD for the remainder of the plot in 1992 changed ($p \leq 0.05$) with increasing spacing (table 1). The QMDs were 4.8, 6.4, 7.5, 8.0, and 8.6 inches for the 6-, 9-, 12-, 15-, and 18-foot spacings, respectively, on the interior plots and 5.0, 6.3, 7.1, 7.7, and 8.2 inches for corresponding spacings on the exterior portion of the plots. Average heights in 1992 did not differ ($p \leq 0.05$) with spacing or location within the plot. Average volumes per tree were highest ($p \leq 0.05$) on the interior plots for all but the 6-foot spacing. Average volume per tree was 1.7, 3.1, 4.1, 4.5, and 5.1 cubic feet on the interior plots for the 6-, 9-, 12- 15-, and 18-foot spacings, respectively, and 1.9, 3.0, 3.7, 4.2, and 4.6 cubic feet on corresponding spacings for the exterior portion of the plots. The interior plots had fewer ($p \leq 0.05$) trees per acre for all but the 15-foot spacing (table 1). This significant difference probably resulted from the loss of two trees from the interior plot on one of the 6-foot spacings, which is equivalent to 101 trees per acre. The loss of two trees from a whole plot with 6-foot spacing would be equivalent to only 9.3 trees per acre. Differences in tree size between interior and exterior portions of the plot were small (although significant, $p \leq 0.05$) in comparison with the effects of spacing. Although these differences were slight, they do indicate an edge effect, which is probably increasing with time. All following results presented in tables and figures, except for mortality, therefore, came from analyses of data from interior plots. A slightly higher percentage of trees died of natural causes on the whole plots rather than the interior plots, so mortality on whole plots during the 27-year study was used in the analysis of variance.

Table 1—Probability of higher *F*-values in the split-plot analyses comparing quadratic mean diameters (QMDs), average heights, average volumes per tree, and trees per acre in 1992 for 2 tree components (C): (1) trees in interior or subplots and (2) trees on the remainder of the plot

		Probabilities of larger *F*-values			
Source	Degree of freedom	QMD	Average height	Average volume per tree	Trees per acre
Spacing (S):					
Linear	1	0.0001	0.6907	0.0001	0.0001
Quadratic	1	.0030	.1451	.0047	.0001
Lack of fit	2	.3858	.7837	.4594	.0001
Error	5				
Tree component (C)	1	.0569	.8555	.0338	.0441
C x S:					
Linear	1	.0485	.7767	.0519	.0383
Quadratic	1	.3445	.6252	.4703	.0960
Lack of fit	2	.6221	.9633	.6144	.3860
Error	5				
MSE:[a]					
Whole plot		.2047	1.7755	.0470	56.5088
Subplot		.0303	.8555	.0338	40.1943

[a] MSE = mean square for error from the analysis of variance.

Tree Size

Average height of interior plot trees for each treatment in fall 1965, five growing seasons after establishment, ranged from 1.2 to 1.6 feet and averaged 1.4 feet (table 2). Twenty-seven years later (fall 1992), these heights ranged from 30.1 to 31.6 feet (averaging 30.9 feet) and did not differ ($p \leq 0.05$) with spacing (table 3). The first year, most of the plot trees were taller than 4.5 feet (fall 1971); QMDs for the interior plot trees averaged 1.3 inches and ranged from 1.0 to 1.5 inches. Twenty-one years later (fall 1992), for all interior plot trees, QMDs ranged from 4.8 to 8.6 inches, basal areas ranged from 53.6 to 148.0 square feet per acre, and total cubic volumes ranged from 674 to 1,993 cubic feet per acre. In fall 1992, QMDs increased curvilinearly ($p \leq 0.05$) as spacing increased, basal areas decreased curvilinearly ($p \leq 0.05$) as spacing increased, and volumes decreased linearly ($p \leq 0.05$) with increased spacing (table 3). In fall 1992, QMDs and basal areas determined from all plot trees differed with spacing in the same manner as QMDs and basal areas determined from interior plot trees (statistics not shown). Volumes determined from all plot trees varied curvilinearly ($p \leq 0.05$, statistics not shown) with spacing and not linearly as was the case for the interior plot trees.

Mortality

Of 1,492 whole plot trees present in 1965, only 28 (1.9 percent) died in the 27-year period. No mortality occurred during some periods. Five of the 240 interior plot trees (2.1 percent) were lost during the 27-year period, but only 4 (1.7 percent) died of natural causes. One tree was accidently cut on an 18-foot spacing treatment, three trees were lost from the 6-foot spacing treatment, and one tree was lost from a 12-foot spacing treatment. Tree mortality for all plot trees during the study in terms of trees per acre decreased ($p \leq 0.05$) curvilinearly with increasing spacing; in terms of basal area per acre, mortality decreased ($p \leq 0.05$) linearly as spacing increased (table 4), although a significant ($p \leq 0.05$) relation between spacing and volume of mortality was not detected. Trees that died of natural causes during any period were much smaller than the trees alive at the start of the period.

Periodic Annual Increments

The PAIs for survivor QMDs increased linearly ($p \leq 0.05$) with increasing spacing and generally decreased ($p \leq 0.05$) from early to later periods (table 5, fig. 1). The QMD PAI means seem to be curvilinearly related to SDI (fig. 2). The increase in QMD PAIs as spacing widened peaked in the 1977-79 period, thereby resulting in significance ($p \leq 0.05$) of the linear term for the period by spacing interaction (table 5). Survivor height PAIs generally decreased ($p \leq 0.05$) with stand age or period and varied differently with spacing in different periods ($p \leq 0.05$) (table 6, fig. 3). Height PAIs seem highest at intermediate spacings only in periods 1965-70, 1971, and 1988-92. Height PAIs seem highest at the widest spacing during the periods 1972-74 and 1975-76, whereas the narrowest spacing had the highest PAI in period 1983-87. These differing patterns result in significance ($p \leq 0.05$) of the linear and quadratic terms for the period by spacing interaction. The PAIs for QMDs determined from all whole-plot trees increased curvilinearly ($p \leq 0.05$) with spacing and generally decreased ($p \leq 0.05$) from early to later periods (statistics not shown). Further, the relation between QMD PAIs from whole plots and spacing varied erratically with period, resulting in significance ($p \leq 0.05$) of the lack of fit term for the period by spacing interaction. The results for height PAIs determined from whole-plot data were similar to height PAIs determined from interior plot data (statistics not shown).

Table 2—Average stand statistics over the 27-year study

Spacing	Trees per acre	QMD[a]	Average height	Basal area	Cubic volume	Stand density index
Feet		*Inch*	*Feet*	*Ft²/acre*	*Ft³/acre*	
			Live trees—fall 1965			
6	1,210	—	1.2	—	—	—
9	538	—	1.6	—	—	—
12	302	—	1.5	—	—	—
15	194	—	1.6	—	—	—
18	134	—	1.3	—	—	—
			Live trees—fall 1970			
6	1,210	—	5.9	—	—	—
9	538	—	7.3	—	—	—
12	302	—	7.2	—	—	—
15	194	—	7.2	—	—	—
18	134	—	6.1	—	—	—
			Live trees—fall 1971			
6	1,210	1.0	6.7	6.0	62.8	20.3
9	538	1.4	8.4	6.1	58.1	18.6
12	302	1.5	8.4	3.7	34.8	11.1
15	194	1.5	8.3	2.4	22.4	7.2
18	134	1.2	7.1	1.1	10.6	3.4
			Live trees—fall 1974			
6	1,210	1.8	9.5	20.6	165.4	61.2
9	527	2.5	12.3	17.6	137.1	46.2
12	302	2.6	12.3	11.5	99.5	29.8
15	194	2.7	12.2	7.9	69.0	20.2
18	134	2.5	11.2	4.6	40.3	12.3
			Live trees—fall 1976			
6	1,210	2.3	11.8	35.6	278.6	95.3
9	527	3.1	14.7	27.2	223.2	67.8
12	302	3.3	14.6	18.4	163.2	44.8
15	194	3.5	14.7	13.0	113.2	31.2
18	134	3.4	13.8	8.7	74.4	21.0
			Live trees—fall 1979			
6	1,210	2.9	15.6	55.7	456.8	143.0
9	527	4.0	19.0	45.5	417.9	105.9
12	296	4.5	18.4	31.8	305.8	72.0
15	194	4.7	18.7	23.6	223.1	52.5
18	132	4.8	17.6	16.2	152.8	36.2
			Live trees—fall 1982			
6	1,210	3.5	18.9	80.0	796.5	193.0
9	527	4.7	22.6	62.8	636.6	140.3
12	290	5.3	22.2	44.0	441.8	95.2
15	194	5.7	22.3	34.4	344.7	73.0
18	132	5.8	21.7	24.8	248.0	52.1

Table 2—Average stand statistics over the 27-year study (continued)

Spacing	Trees per acre	QMD[a]	Average height	Basal area	Cubic volume	Stand density index
Feet		*Inch*	*Feet*	*Ft²/acre*	*Ft³/acre*	
			Live trees—fall 1987			
6	1,160	4.4	25.2	119.8	1,440.1	272.6
9	527	5.7	27.6	93.0	1,161.0	197.4
12	290	6.7	27.0	70.2	864.8	143.1
15	194	7.1	27.0	53.2	622.0	106.6
18	132	7.5	26.4	40.8	469.6	82.7
			Live trees—fall 1992			
6	1,160	4.8	30.1	148.0	1,993.4	327.8
9	527	6.4	31.6	116.0	1,643.4	239.2
12	290	7.5	31.1	88.9	1,195.4	175.7
15	194	8.0	31.0	67.0	877.2	130.3
18	132	8.6	30.6	53.6	673.8	102.0

[a] QMD = quadratic mean diameter.

Table 3—Probability of higher *F*-values in the analyses of variance of quadratic mean diameter (QMD), average height, basal area, and total cubic volume 27 years after thinning to 5 different spacings

Source	Degrees of freedom	Probabilities of larger *F*-values: QMD	Average height	Basal area	Cubic volume
Spacing:					
Linear	1	0.0001	0.8314	0.0001	0.0001
Quadratic	1	.0069	.2538	.0340	.1296
Lack of fit	2	.3394	.7116	.9565	.5428
Error	5				
MSE[a]		.0412	.9940	30.6823	7771.3650
CV%[b]		2.88	3.74	5.85	6.91

[a] MSE = mean square for error form the analysis of variance.
[b] CV% = coefficient of variation.

Table 4—Probabilities of larger *F*-values in the analyses of variance of mortality that occurred during 27 years of observation on whole plots

Source	Degrees of freedom	Probabilities of larger *F*-values: Trees per acre	Basal area	Cubic volume
Spacing:				
Linear	1	0.0023	0.0439	0.0624
Quadratic	1	.0114	.1519	.2078
Lack of fit	2	.2389	.4860	.3592
Error	5			
MSE[a]		23.3210	.02795	3.4723
CV%[b]		57.02	99.80	117.64

[a] MSE = mean square for error from the analysis of variance.
[b] CV% = coefficient of variation.

Table 5—Probability of higher *F*-values in the repeated measures analyses of periodic annual increments (PAIs) for survivor quadratic mean diameter (QMD), basal area, and total cubic volume

		Probabilities of larger *F*-values				
		PAI				
			Basal area		Volume	
Source	Degrees of freedom	QMD	Gross	Net	Gross	Net
Spacing (S):						
Linear	1	0.0001	0.0001	0.0001	0.0001	0.0001
Quadratic	1	.1348	.0067	.0061	.0905	.0856
Lack of fit	2	.2687	.5367	.6072	.7359	.7012
Error	5					
Period (P)	5	.0001	.0001	.0001	.0001	.0001
P x S:						
Linear	5	.0237	.0461	.0482	.0001	.0001
Quadratic	5	.1125	.1616	.1512	.0038	.0033
Lack of fit	10	.9983	.9006	.9014	.2373	.2429
Error	25					
MSE:[a]						
Whole plot		.00046	.2148	.2647	28.2545	72.3069
Subplot		.00052	.2664	.2076	77.0488	28.1590

[a] MSE = mean square for error for the repeated measures analysis.

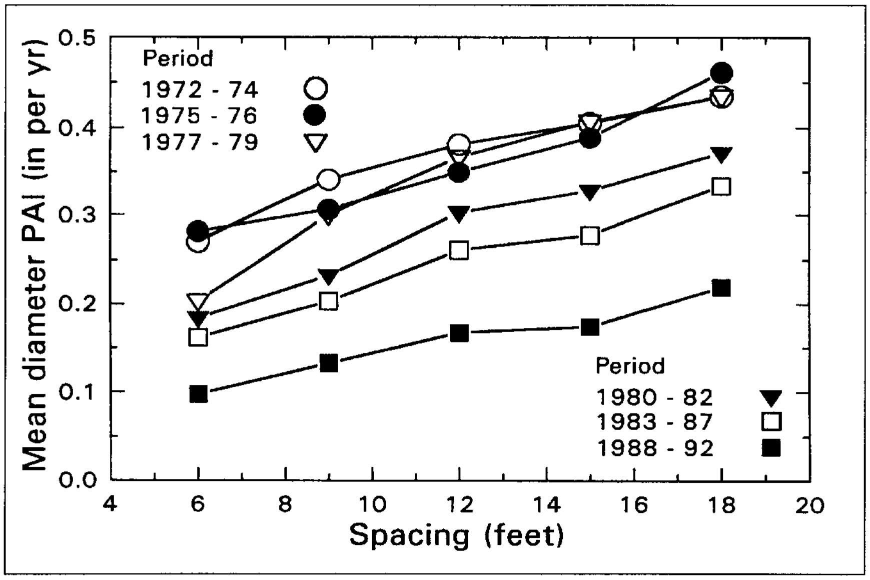


Figure 1—Relation of survivor PAIs for QMD to spacing for the six periods when all trees were greater than 4.5 feet in height.

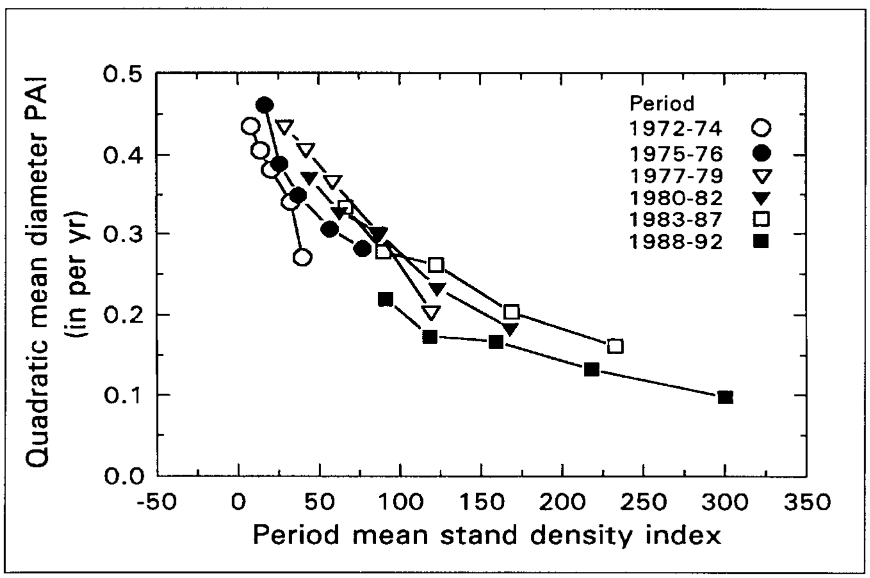


Figure 2—Relation of survivor PAIs for QMD to mean period SDIs for the six periods when all trees were greater than 4.5 feet in height.

Table 6—Probability of higher *F*-values in the repeated measures analyses of periodic annual increments (PAIs) for survivor average heights

Source	Degrees of Freedom	Probabilities of larger *F*-values: PAI—average height
Spacing (S):		
Linear	1	0.1171
Quadratic	1	.1525
Lack of fit	2	.4355
Error	5	
Period (P)	7	.0001
P x S:		
Linear	7	.0016
Quadratic	7	.0027
Lack of fit	14	.7152
Error	25	
MSE:[a]		
Whole plot		.01302
Subplot		.00874

[a] MSE = mean square for error from the repeated measures analysis.

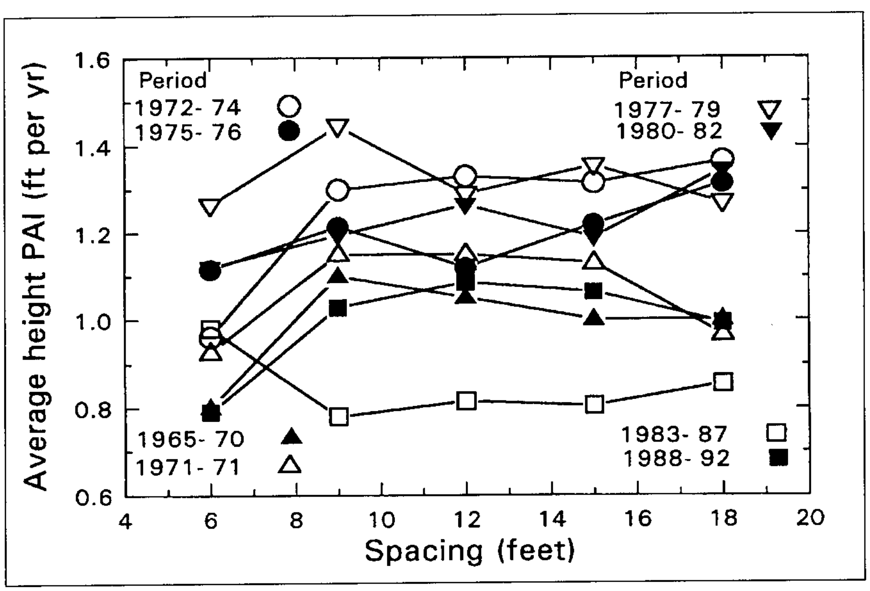


Figure 3—Relation of survivor PAIs for average height to spacing for the eight periods of study.

Because of the small size and low numbers of the trees that died, net and gross PAIs were nearly identical for both basal area and volume. The PAIs for basal area decreased curvilinearly ($p \leq 0.05$) as spacing increased, and the PAIs for volume decreased linearly ($p \leq 0.05$) as spacing increased (table 5, figs. 4 and 5). The PAIs for basal area and volume also differed ($p \leq 0.05$) with period, and increases in volume PAIs as spacing decreased were greater during later periods as shown by the significance ($p \leq 0.05$) of the linear term for the period by spacing interaction (table 5). These PAIs seemed to be linearly related to SDI for most periods (figs. 6 and 7). Basal area PAIs determined from whole-plot data also varied curvilinearly ($p \leq 0.05$) with spacing, and volume PAIs determined from whole plots varied curvilinearly ($p \leq 0.05$) with spacing. Variations in these PAIs with period were similar for both whole plots and interior plots (statistics not shown).

Volumes in Largest Trees

An 18-foot spacing has 134 trees per acre. Volumes of the 134 trees per acre with the largest diameters on both interior plots and whole plots increased curvilinearly ($p \leq 0.05$) with increasing spacing (table 7, fig. 8, whole plot statistics and data not shown). The fall 1992 volume of the largest 134 trees per acre in the 6-foot spacing from interior plots was only 36 percent of the volume of all the interior plot trees in the 18-foot spacing. The fall 1992 volume of the largest 134 trees per acre in the 6-foot spacing using whole-plot data was, however, 67 percent of the volume of all whole-plot trees on the 18-foot spacing.

Crown Characteristics

Crown widths ranged from 3.6 to 5.3 feet in fall 1971. By fall 1992, crown widths ranged from 7.5 to 16.7 feet (fig. 9). Crown widths increased ($p \leq 0.05$) curvilinearly with increasing spacing (table 8), and changes in this quadratic surface with time were not detected. Fall 1971 crown cover ranged from 4.6 to 28.7 percent. Fall 1992 crown cover varied from 67.3 to 100 percent. Crown cover decreased ($p \leq 0.05$) linearly as spacing increased and increased ($p \leq 0.05$) more rapidly with time at wider spacings (table 8, fig. 10). Plots of percentage of crown cover as a function of SDI (fig. 11) indicate a curvilinear relation with 50, 70, and 100 percent crown cover attained at SDIs of about 80, 120, and 190, respectively.

Extra Trees

Some natural regeneration occurred on the 15- and 18-foot spacing treatments after study establishment. Most of this later regeneration was in the 18-foot spacings. These slender thinned-crowned trees were cut in fall 1982 before they were thought to be competitive enough to alter the development of the older plot trees. Little regeneration has taken place since that time.

Simulation Outcomes

The 6-foot spacing was thinned at a breast high age of 25 years (table 9) because stand densities were greater than 75 percent of the normal SDI (277). Because no 9-inch trees were present, SDI after thinning was 139 (about 50 percent of normal). Fourteen years later, stand density for this spacing exceeded 75 percent of normal, but still no 9-inch trees were present, and the SDI after thinning was 139. Nine years after the second thinning, 9-inch trees were present, and the SDI had exceeded 170, and so a third thinning occurred, thereby reducing the SDI to 112. Twenty-one years after the third thinning, the SDI again exceeded 170, and the stand was thinned again. At final removal, SDI was 170. This spacing produced the least Scribner board feet with the lowest discounted values, and the highest amount of merchantable cubic volume with the highest discounted values.

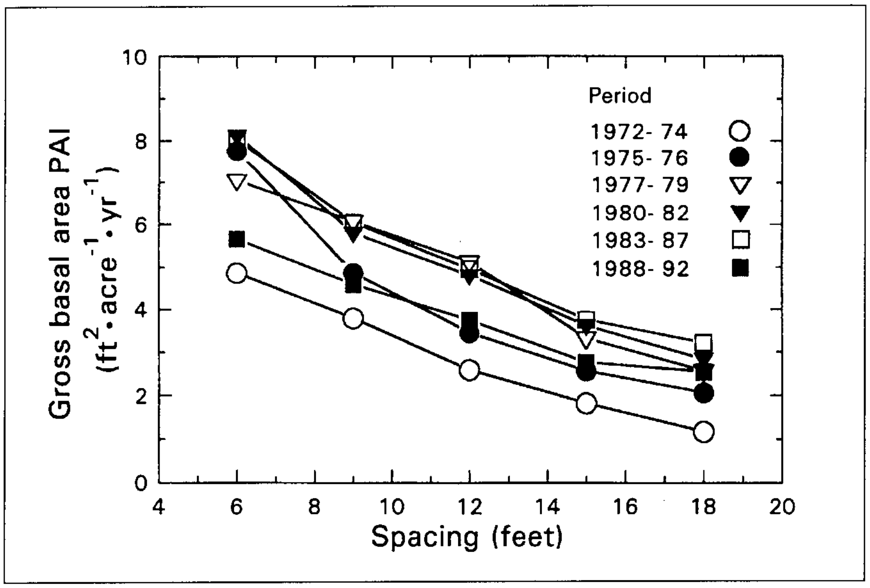


Figure 4—Relation of gross basal-area PAI to spacing for the six periods when all the trees were greater than 4.5 feet in height.

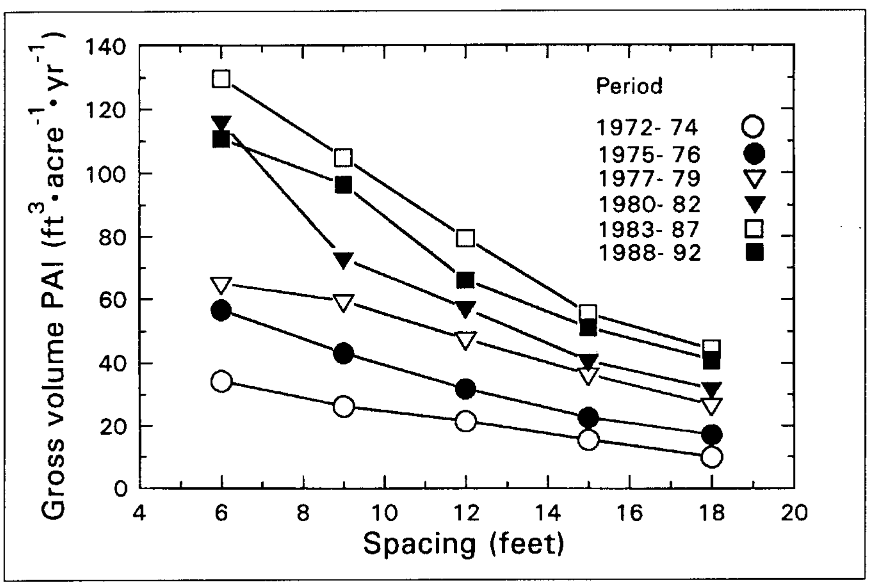


Figure 5—Relation of gross total cubic-volume PAI to spacing for the six periods when all the trees were greater than 4.5 feet in height.

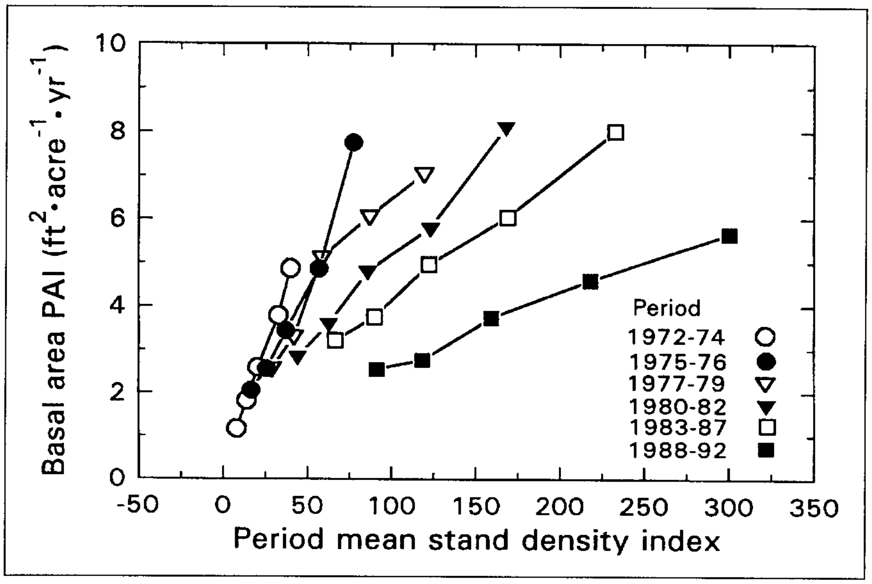


Figure 6—Relation of gross basal-area PAI to period mean SDI for the six periods when all the trees were greater than 4.5 feet in height.

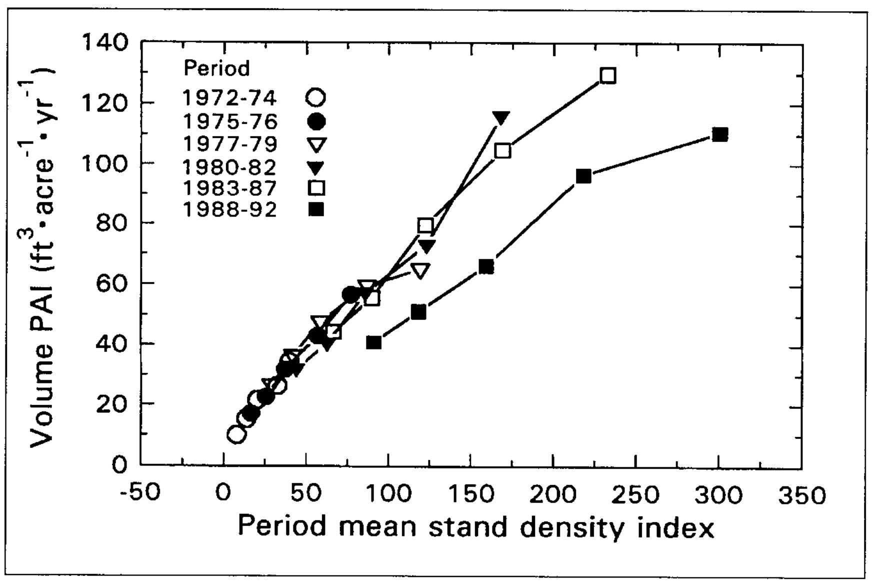


Figure 7—Relation of gross total cubic-volume PAI to period mean SDI for the six periods when all the trees were greater than 4.5 feet in height.

Table 7—Probability of higher *F*-values in the analyses of variance of percentage of 1992 cubic volume of the narrowest spacing in the 134 trees with the largest diameters for each spacing

Source	Degrees of freedom	Probability of higher *F*-values
Spacing:		
Linear	1	0 .0001
Quadratic	1	.0011
Lack of fit	2	.1478
Error	5	
MSE[a]		.0003657
CV%[b]		6.88

[a] MSE = mean square for error from the analysis of variance.
[b] CV% = coefficient of variation.

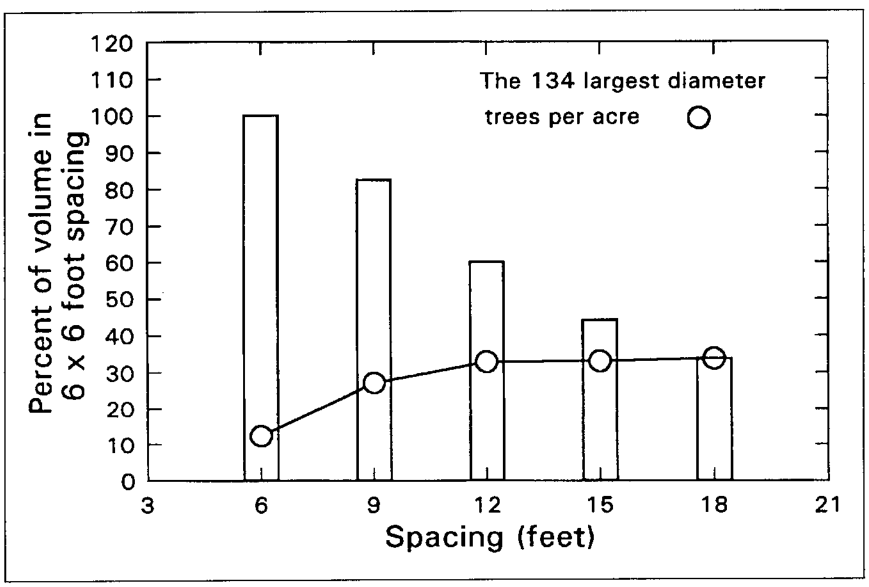


Figure 8—Percentage of 1992 total cubic volume in the narrowest spacing for each of the spacings and for the 134 largest diameter trees in each spacing. An 18-foot spacing has 134 trees per acre.

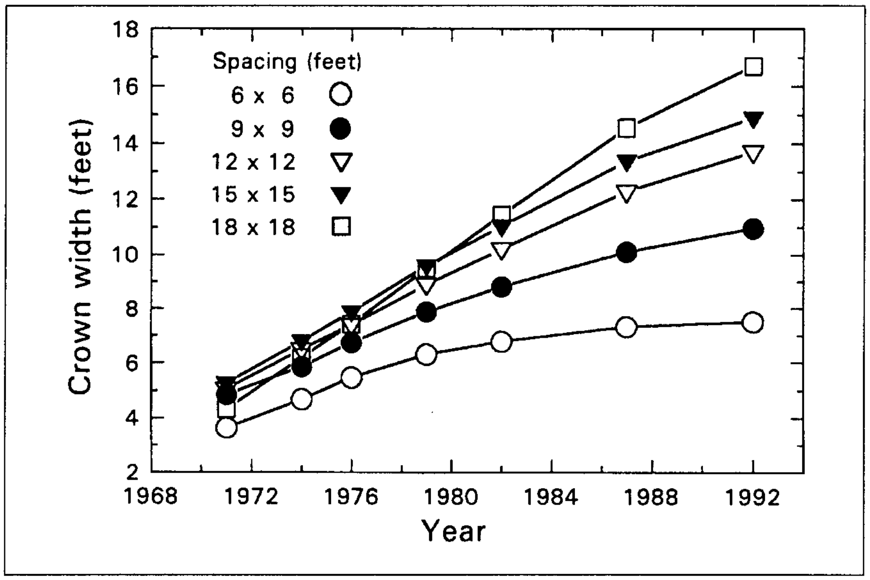


Figure 9—Development of crown width for each spacing with time.

Table 8—Probability of higher *F*-values in the repeated measures analyses of crown width and crown cover

Source	Degrees of freedom	Probabilities of higher *F*-values: Crown width	Crown cover
Spacing (S):			
Linear	1	0.0001	0.0001
Quadratic	1	.0007	.1820
Lack of fit	2	.9308	.9511
Error	5		
Time (T)	6	.0001	.0001
T x S:			
Linear	6	.0001	.0001
Quadratic	6	.8677	.0001
Lack of fit	12	.5109	.2690
Error	30		
MSE:[a]			
Whole plot		.2898	.0029
Subplot		.0875	.0006

[a] MSE = mean square for error from the repeated measures analysis.

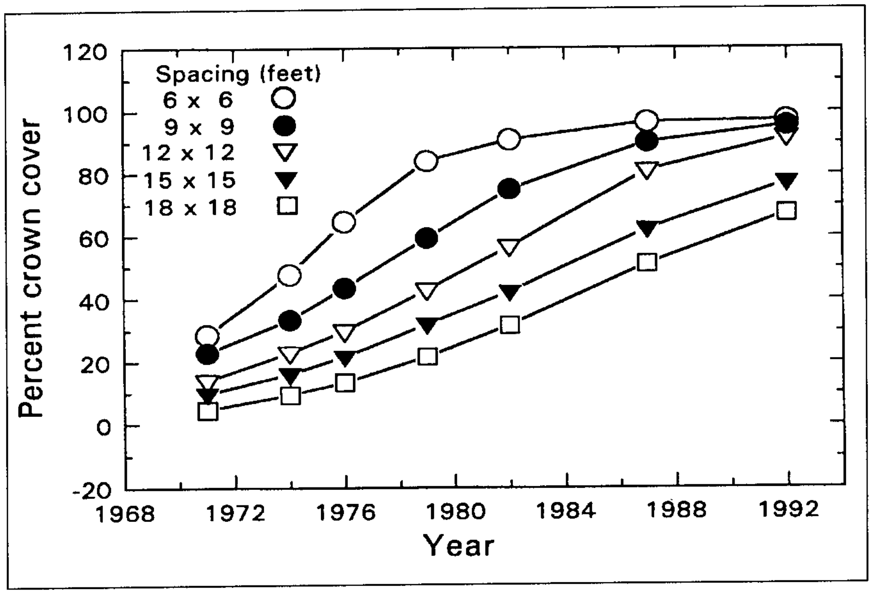


Figure 10—Development of crown cover for each spacing with time.

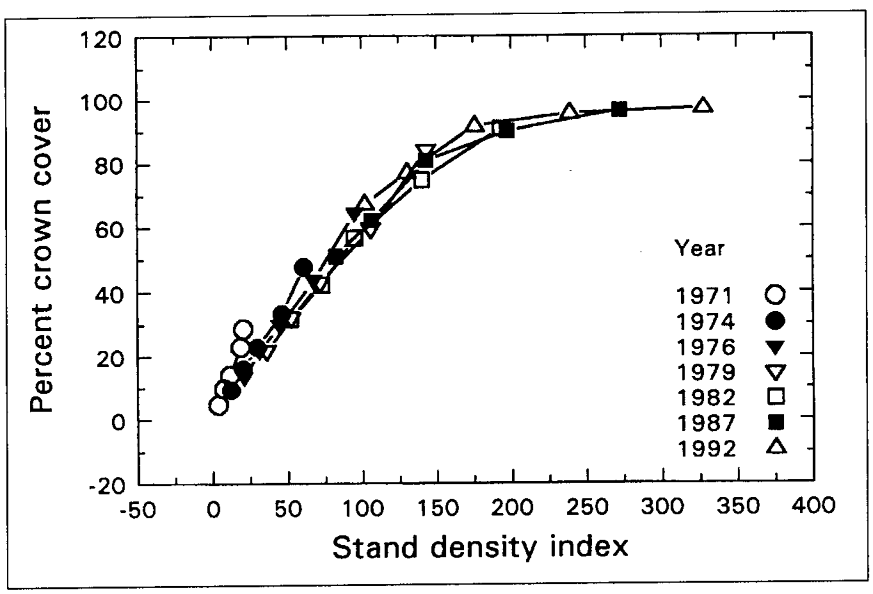


Figure 11—Relation of crown cover to SDI for 7 different years of measurement.

Table 9—Breast high age of thinning or final removal, volumes removed and their values discounted to the year of establishment, tree numbers, quadratic mean diameters (QMDs), and stand densities for stand projections of different spacings

		Board-foot volume[a]		Cubic volume[b]		Trees			Stand density index	
Spacing	Thinning age	Removed	Discounted value	Removed	Discounted value	Removed	Left	QMD	Before thinning	After thinning
Ft	*Years*	*Bd. ft*	*Dollars*	*Ft^3*	*Dollars*			*Inches*		
6	25	0	0.00	1,248	259.76	617	488	4.9	238	139
	39	653	9.33	685	53.10	170	319	6.3	211	139
	48	1,172	14.86	671	35.97	112	205	7.1	173	112
	69	2,762	23.35	859	24.00	72	133	9.1	172	112
	100	12,730	40.22	3,010	36.25	133	0	11.6	170	—
Total		17,317	87.75	6,473	409.06					
9	25	345	8.98	710	97.44	222	304	6.4	239	139
	39	1,931	42.70	928	88.94	139	165	8.1	206	112
	57	2,625	40.69	774	50.32	56	109	10.3	170	112
	84	4,449	26.33	1,020	17.95	37	71	13.0	171	112
	100	12,166	38.44	2,588	31.15	71	0	14.5	136	—
Total		20,885	145.79	5,856	273.07					
12	28	932	31.24	607	66.76	121	115	8.0	192	112
	43	1,948	51.80	643	40.82	59	111	10.2	171	11
	65	3,676	44.07	888	28.56	38	114	13.0	172	114
	100	16,229	51.28	3,283	39.51	72	0	16.6	172	—
Total		22,758	178.39	5,421	175.67					

Table 9—Breast high age of thinning or final removal, volumes removed and their values discounted to the year of establishment, tree numbers, quadratic mean diameters (QMDs), and stand densities for stand projections of different spacings (continued)

		Board-foot volume[a]		Cubic volume[b]		Trees			Stand density index	
Spacing	Thinning age	Removed	Discounted value	Removed	Discounted value	Removed	Left	QMD	Before thinning	After thinning
Ft	*Years*	*Bd. ft*	*Dollars*	*Ft*^{3}	*Dollars*			*Inches*		
15	35	1,419	46.93	564	45.04	69	125	9.5	174	112
	53	2,804	55.98	749	35.56	43	82	12.1	171	112
	79	4,632	32.07	994	20.09	28	54	15.3	170	112
	100	13,585	42.93	2,698	32.48	54	0	17.5	142	—
Total		22,440	177.91	5,005	133.17					
18	42	2,098	64.49	621	40.01	45	87	11.7	170	112
	64	3,809	49.40	863	29.42	30	57	14.9	170	112
	100	17,051	53.88	3,298	39.69	57	0	19.0	174	—
Total		22,958	167.77	4,782	109.12					

[a] Scribner board-foot volume to a 5-inch top inside bark.
[b] Merchantable cubic volume to a 3-inch top inside bark.

The 9-foot spacing also was thinned at a breast high age of 25 years because SDI exceeded 75 percent of normal. No 9-inch trees were present, and SDI thus was reduced to 139. The 12-foot spacing had stand densities exceeding 170 and some 9-inch trees at the start of the simulation, and so thinnings were immediate also. The 15- and 18-foot spacing densities did not exceed SDIs of 170 for several years after the start of simulation. The 9-foot spacing had four thinnings before final removal. The 12- and 15-foot spacings had three thinnings, and the 18-foot spacing had two thinnings before final removal.

Merchantable cubic volumes and their discounted values decreased with increasing spacing. Scribner board-foot volumes increased as spacings increased from 6 to 12 feet but then decreased slightly as spacing increased to 18 feet. The discounted values per acre for Scribner board feet increased as spacing increased to 12 feet, decreased $0.48 as spacing increased to 15 feet, and then decreased $10.21 as spacing increased to 18 feet. Simulations made by using all whole-plot trees (data not shown) produced similar basal-area and cubic-volume yields. Discounted cubic- and board-foot values from whole plot simulations versus interior plot simulations were higher for the 6-foot spacing and lower for the remaining spacings.

Discussion and Conclusions

The study was originally designed to examine the development of height and diameter of individual trees at different spacings. The interior plots containing the trees originally designated to be measured normally would be considered too small to biologically describe the growth and yield characteristics of stands. Comparison of tree sizes after 27 years between trees on interior and exterior portions of the plots indicate an edge effect which produced slightly smaller trees in the interior plot than in the plot remainder for the 6-foot spacing and slightly larger trees in the interior plot than in the plot remainder for the 18-foot spacing. The PAIs and mortality rates determined from whole plot and interior plot data were similar and indicated that the growth data interior plots in this study are reasonable; the slightly different patterns of PAIs with period for whole plots and interior plots can be attributed to edge effect.

Early stand management regimes for lodgepole pine depend on anticipated mortality, anticipated fill-in because of later natural regeneration, and value of desired future products. The quality of wildlife habitat at various stages of stand development is probably the product most difficult to evaluate.

Johnston and Polack (1990) report that juvenile lodgepole pine is notoriously susceptible to various pests, including rusts, insects, and small mammals, and often additional trees should be planted to offset anticipated losses. They found that 16 percent of the sample trees in a plantation spacing study died or were severely deformed during the first 20 years after planting and that this mortality was not related to spacing. Johnstone and Pollack (1990) recommend a minimum planting density of 648 trees per acre to offset mortality. The trees in this study, however, have remained remarkably healthy, and what little mortality occurred seems suppression related and confined almost entirely to the narrowest spacing (table 1). Leaving additional trees under conditions similar to those found in this study would be unnecessary.

Mean diameter growth increased dramatically as spacing increased, whereas total cubic-volume growth decreased with increased growing space, similar to results in other spacing studies in lodgepole pine (Johnstone 1985) and other species. Natural stands need spacing control if large trees are to be grown in reasonable periods. Height did not differ significantly with spacing ($p \leq 0.05$) 27 years after treatment, but the effect of spacing on height growth differed with period. Mixed results for response of height growth to stand density have been reported for other studies in lodegepole pine (Johnstone 1985), and site quality, stand age, and past stand history all may influence the height growth response of lodgepole pine to thinning.

The linear or near-linear relation of PAIs of both basal area and volume to SDI (figs. 6 and 7) was unexpected, particularly for the last period when SDIs for the highest density exceeded 277. An SDI of 277 is considered to depict normal stocking for lodgepole pine in south-central Oregon (Cochran and others 1994). The normal stocking level for the plant community of this study area may be considerably higher than 277. The equation predicting volume growth in the simulation model depicts a curvilinear relation between cubic volume PAI and SDI. The simulation of the plots may have produced yields that were too low.

The growth of a fixed number of largest trees per acre was reduced by the presence of smaller trees, thereby indicating that density management speeds the growth of even the largest trees in the stand. Natural stands of lodgepole pine tend to stagnate, and a self-thinning process which maintains stand densities at near-normal stocking levels and allows reasonable growth rates for dominant and codominant trees cannot be expected to occur.

Height, crown cover, canopy depth, and stem density are of major to minor influence in affecting temperature, wind, and radiation and thus, the microclimate for deer (Bergen 1971, 1974; Gary 1974; Geiger 1966; Reifsnyder and Lull 1965; Verme 1965). Verme (1965) states that optimum microclimates for deer probably would begin at a minimum crown cover of 50 percent. Fifty percent crown cover was attained in 1974, 1977, 1981, 1984, and 1987 for the 6-, 9-, 12-, and 18-foot spacings, respectively (fig. 10) when SDIs were about 80 (fig. 11). Black and others (1976), however, define thermal cover for deer and elk as a coniferous stand at least 40 feet tall with an average crown cover exceeding 70 percent. Heights did not reach 40 feet for any of the spacings during the 27 years of observation, and the 18-foot spacing never acquired a crown cover of 70 percent. A crown cover of 70 percent was attained in 1977 for the 6-foot spacing and in 1981, 1985, and 1990 for the 9-, 12-, and 15-foot spacings (fig. 10) when SDIs were about 120. The crown width for any given tree size depends in part on genetics and on past stand densities. The relation between crown cover and SDI in this study (fig. 11) is conditioned to a large extent by the early spacing, which allowed wide crowns to develop. The relation between percentage of crown cover and SDI for lodgepole pine reported by Smith and Long (1987) is much different than that found for this study. An SDI of 252 is necessary for 50 percent crown cover, and an SDI of 552 is necessary for a 70 percent crown cover according to the equation they present (Smith and Long 1987, table 1).

Probable conflicts among anticipated future timber values, value for wildlife habitat, and future stand susceptibility to mountain pine beetle should be recognized when making decisions about timing and degree of early spacings. Simulation showed the greatest merchantable cubic-foot yield and value would be produced at the narrowest spacing, and the greatest Scribner board-foot value and volume would be produced at wider spacings. Growing lodgepole pine at narrow spacings should be viewed with caution. Sales will be necessary at critical times to reduce risk to mountain pine beetles. These stands with narrow crowned trees may never have the 50 to 70 percent crown cover after the first commercial thinning that some wildlife biologists think is necessary for thermal cover. Selling large stems is usually easier than selling small stems, and fewer stand entries are necessary with large target diameters over the life of the stand. The wide spacings necessary to produce sawtimber-sized trees early will result in large limb sizes and perhaps greater stem taper, and value for the same diameter thus may be reduced with increased spacing (Ballard and Long 1988). Fill-in from later natural regeneration also can be a problem at wider spacings. Eighteen-foot spacings in this study area may not be practical because of later establishment of excessive numbers of trees. If the relation between crown cover and SDI (fig. 11) found in this study holds for older stands, crown cover should be 50 percent or above after commercial thinning for stands with wide initial spacings, provided the leave trees are equally spaced, because SDIs after thinning are 112 (table 9) or above. Delaying precommercial thinning in dense stands until trees are 9 feet or more in height, as is often done (Johnstone 1985), may result in crowns so narrow that 50 percent crown cover is never attained within the density limit SDI 170 imposed to reduce risk to mountain pine beetle (Smith and Long 1987, table 1).

Metric Equivalents

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 mile = 1.609 kilometers

1 acre = 0.4047 hectare

1 tree per acre = 2.47 trees per hectare

1 square foot = 0.09290 square meter

1 square foot per acre = 0.2296 square meter per hectare

1 cubic foot per acre = 0.06997 cubic meter per hectare

Literature Cited

Ballard, Louis A.; Long, James N. 1988. Influence of stand density on log quality of lodgepole pine. Canadian Journal of Forest Research. 18(7): 911-916.

Barrett, J.W. 1961. Response of 55-year-old lodgepole pine to thinning. Res. Note PNW-206. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 8 p.

Basile, J.V. 1975. Forage productivity in the lodgepole pine type. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems: Proceedings of a symposium; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University: 246-263.

Bergen, J.D. 1971. Vertical profiles of wind speed in a pine stand. Forest Science. 17(3): 314-321.

Bergen, J.D. 1974. Vertical air temperature profiles in a pine stand: spatial variation and scaling problems. Forest Science. 20(1): 64-73.

Black, H.; Scherzinger, R.; Thomas, J.W. 1976. Relationships of Rocky Mountain elk and Rocky Mountain mule deer habitat to timber management in the Blue Mountains of Oregon and Washington. In: Heib, Susan R., ed. Proceedings, elk-logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho: 11-31.

Cochran, P.H.; Geist, J.M.; Clemens, D.L. [and others]. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southwestern Washington. Res. Note PNW-RN-513. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 21 p.

Cole, D.M. 1983. Canopy development in lodgepole pine: implications for wildlife studies and multiple resource management. Gen. Tech. Rep. INT-139. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 13 p.

Dahms, Walter G. 1975. Gross yield of central Oregon lodgepole pine. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems: Proceedings of a symposium; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University: 208-232.

Dahms, Walter G. 1983. A growth simulation model for lodgepole pine in central Oregon. Res. Pap. PNW-302. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 22 p.

Dealy, J.E. 1975. Management of lodgepole pine ecosystems for range and wildlife. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems: Proceedings of a symposium; 1973 October 9-11; Pullman WA. Pullman, WA: Washington State University: 556-568.

Gary, H.L. 1974. Canopy weight distribution affects wind speed and temperature in a lodgepole pine forest. Forest Science. 20(4): 369-371.

Geiger, R. 1950. The climate near the ground. [reprinted 1966] Cambridge, MA: Harvard University Press. 611 p.

Hamilton, David A.; Edwards, Bruce M. 1976. Modeling the probability of individual tree mortality. Res. Pap. INT-185. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

Johnstone, W.D. 1985. Thinning lodgepole pine. In: Baumgartner, D.M.; Krebill, R.G.; Arnott, J.T.; Weetman, G.F., eds., comps. Lodgepole pine: the species and its management: Proceedings of a symposium; 1984 May 8-10; Spokane, WA.; 1984 May 14-16; Vancouver, BC. Pullman, WA: Washington State University: 253-262.

Johnstone, W.D.; Pollack, J.C. 1990. The influence of espacement on the growth and development of a lodgepole pine plantation. Canadian Journal of Forest Research. 20(10): 1631-1639.

Mitchell, R.G.; Waring, R.H.; Pitman, G.B. 1983. Thinning lodgepole pine increases tree vigor and resistance to mountain pine beetle. Forest Science. 29(1): 204-211.

Mitchell, Russel G.; Preisler, Halgonoush K. 1991. Analysis of spatial patterns of lodgepole pine attacked by outbreak populations of mountain pine beetle. Forest Science. 37(5): 1360-1408.

Peterson, William C.; Hibbs, David E. 1989. Adjusting stand density management guides for sites with low stocking potential. Western Journal of Applied Forestry. 4(2): 62-65.

Reifsnyder, W.E.; Lull, H.W. 1965. Radiant energy in relation to forests. Tech. Bull. 1344. Washington, DC: U.S. Department of Agriculture. 111 p.

SAS Institute. 1988. SAS/STAT users guide, release 6.03 ed. Cary, NC. 1028 p.

Schumacher, Francis X.; Hall, Francisco dos Santos. 1933. Journal of Agricultural Research. 47(9): 719-734.

Smith, Frederick W.; Long, James N. 1987. Elk hiding and thermal cover guidelines in the context of lodgepole pine stand density. Western Journal of Applied Forestry. 2(1): 6-10.

Verme, L.J. 1965. Swamp conifer deer yards in northern Michigan, their ecology and management. Journal of Forestry. 63(7): 523-529.

Cochran, P.H.; Dahms, Walter G. 1998. Lodgepole pine development after early spacing in the Blue Mountains of Oregon. Res. Pap. PNW-RP-503. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 24 p.

Seedlings were thinned to spacings of 6, 9, 12, 15, and 18 feet and measured periodically. Twenty-seven years after treatment, quadratic mean diameters increased curvilinearly ($p \leq 0.05$) as spacing increased, but total height did not differ significantly ($p \leq 0.05$) with spacing. Corresponding basal areas decreased curvilinearly ($p \leq 0.05$), and cubic volumes decreased linearly ($p \leq 0.05$) as spacing increased. All periodic annual increments differed with period or age. Periodic annual increments for mean diameter and basal area varied curvilinearly ($p \leq 0.05$), whereas volume increments varied linearly ($p \leq 0.05$) with spacing for each period. Height increments were greatest at intermediate spacings during some periods, at wide spacings during other periods, and at the narrowest spacing during one period. Crown widths increased ($p \leq 0.05$) as spacing widened. Fifty percent crown cover was attained at a stand density index of about 80 for all spacings. Simulation to a breast high age of 100 years indicated that the most merchantable cubic volume was produced at the 6-foot spacing but that the 12-, 15-, and 18-foot spacings produced about the same board-foot volume.

Keywords: Growth, lodgepole pine, Blue Mountains (Oregon), thinning, simulation.

Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, Oregon 97208-3890

U.S. Department of Agriculture
Pacific Northwest Research Station
333 S.W. First Avenue
P.O. Box 3890
Portland, OR 97208

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1998	Research Paper

4. TITLE AND SUBTITLE
Lodgepole Pine Development After Early Spacing in the Blue Mountains of Oregon

5. FUNDING NUMBERS

6. AUTHOR(S)
Cochran, P.H., and Walter G. Dahms

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Pacific Northwest Research Station
Communications Group
P. O. Box 3890
Portland, OR 97208-3890

8. PERFORMING ORGANIZATION REPORT NUMBER
FSRP-PNW-503

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Same as number 7

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Release unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Seedlings were thinned to spacings of 6, 9, 12, 15, and 18 feet and measured periodically. Twenty-seven years after treatment, quadratic mean diameters increased curvilinearly ($p \leq 0.05$) as spacing increased, but total height did not differ significantly ($p \leq 0.05$) with spacing. Corresponding basal areas decreased curvilinearly ($p \leq 0.05$), and cubic volumes decreased linearly ($p \leq 0.05$) as spacing increased. All periodic annual increments differed with period or age. Periodic annual increments for mean diameter and basal area varied curvilinearly ($p \leq 0.05$), whereas volume incrementsvaried linearly ($p \leq 0.05$) with spacing for each period. Height increments were greatest at intermediate spacing during some periods, at wide spacings during other periods, and at the narrowest spacing during one period. Crown widths increased ($p \leq 0.05$) as spacing widened. Fifty percent crown cover was attained at a stand density index of about 80 for all spacings. Simulation to a breast high age of 100 years indicated that the most merchantable cubic volume was produced at the 6-foot spacing but that the 12-, 15-, and 18-foot spacings produced about the same board foot volume.

14. SUBJECT TERMS
Growth, lodgepole pine, Blue Mountains (Oregon), thinning, simulation.

15. NUMBER OF PAGES
24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	