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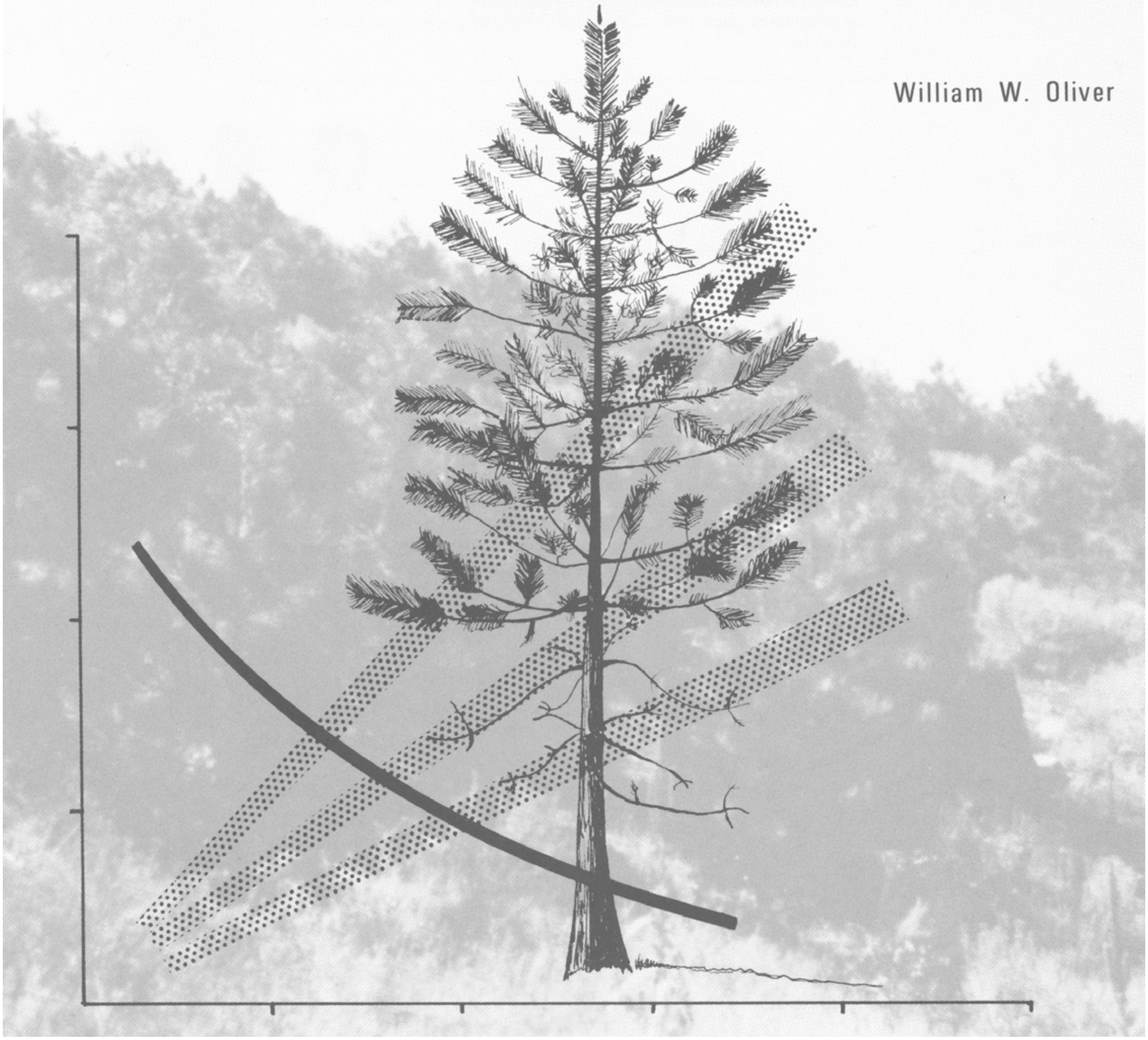
Fifteen-year growth patterns after thinning a ponderosa-Jeffrey pine plantation in northeastern California

William W. Oliver



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In a pole-size ponderosa and Jeffrey pine plantation, the Modoc National Forest thinned trees on six unrepheated plots to a wide range of stand densities. Measurements of growth patterns over the 15 years since thinning provide a rare opportunity to evaluate the current practice of making one precommercial thinning in such stands.

The plantation, on the west slope of the Warner Mountains in extreme northeastern California, has a site index of 50 feet (15 m) at 50 years. on the average. Trees were planted to an 8-foot (2.4-m) spacing in 1932. Survival after six growing seasons was 80 percent. Plots were thinned between 1959 and 1961 when the stand was 28 to 30 years old, 6 inches (15 cm) in diameter, and 18 feet (5 m) tall. After about 15 years, mean annual growth during each of three periods of about 5 years was analyzed.

Considered on this basis, periodic annual diameter growth was influenced markedly by thinning and the subsequent buildup of stand basal area. As basal area increased from 13 square feet to 147 square feet per acre (3.0 to 33.7 m^2/ha), diameter growth decreased at a decreasing rate from 0.5 to 0.1 inch (1.3 to 0.3 cm) per year. Basal area growth, however, was linearly related to stand basal area and differed among growth periods. Annual growth during the first period ranged from 2 square feet per acre (0.46 m^2/ha) in the most heavily thinned plot to 6.5 square feet (1.49 m^2/ha) in the unthinned plot. In plots lightly thinned, it tended to be less during the second period and was significantly less during the third period for a given stand density. Most likely, growth declined because the plantation had passed the age when periodic annual basal area growth culminates.

Periodic annual height growth was associated with stand density. The average tree in plots heavily thinned grew more rapidly in height than the average tree in plots unthinned or thinned lightly, especially during the third period. Apparently, response was delayed until the released trees built up their crowns sufficiently to produce the additional food required for increased height growth.

Volume production levels rose rapidly with higher plot basal areas up to about 76 cubic feet per acre (5.32 m^3/ha) at 70 square feet of basal area per acre (16. 1 m^2/ha). Production levels on plots with basal areas of above 70 square feet rose less rapidly to about 97 cubic feet per acre (6.79 m^3/ha) annually at 110 square feet (25.2 m^2/ha), and then remained virtually static. A basal area of 110 square feet per acre (25.2 m^2/ha) seems optimum for timber production in this plantation since it represents nearly maximum volume production on the minimum amount of growing stock.

Standing merchantable volume built up rapidly on all plots over the 15 years of growth. Ingrowth was the major contributor during the first period and then declined in importance. Board-foot production was highest at a constant stand density during each period only when density was expressed as number of trees per acre rather than basal area. Production levels were highest at between 200 and 300 trees per acre (494 to 741 trees/ha)—about the optimum density for cubic volume production. also.

The performance of this ponderosa and Jeffrey pine plantation over about a 15-year period can be projected to evaluate a common thinning practice. I predict that 25 years after this plantation of 7-inch (17.8 cm) d.b.h. trees was thinned, it should reach a merchantable size of 12 inches (30.5 cm) with a basal area of 126 square feet per acre (28.9 m^2/ha). A commercial thinning from below could yield 1200 board feet per acre of trees 9 to 12 inches (22.9 to 30.5 cm) and leave the stand at optimum density for continued volume production.

Most forest managers plan only one precommercial thinning, in ponderosa pine or Jeffrey pine plantations in California. They hope that one thinning will be adequate until the trees reach sawlog size, when the merchantable material removed will pay for thinning and provide a return on investment. Recommendations of stand densities to meet this objective are based upon meager experience and research results, however. Thinning in plantations or in natural stands to the wider spacings now being practiced has not yet provided information on long-term growth trends. Most research on stand density reports short-term growth responses or is based on frequent rethinnings rather than only one.

An unusual opportunity to evaluate the practice of a single precommercial thinning occurred when the Modoc National Forest established six plots in a plantation of pole-size ponderosa and Jeffrey pine for thinning to a wide range of stand densities. This paper reports growth patterns on these plots after about 15 years. Measurements taken at periods of approximately 5 years were analyzed, and relationships of periodic annual increments in diameter, height, basal area, and cubic volume to stand density and years since thinning were determined.

STUDY AREA

The plantation is at 5400-feet (1 647-m) elevation on the west slope of the Warner Mountains, 27 miles (43 km) northeast of Alturas, Modoc County, California. The plots lie on flat land or gentle north-facing slopes at the base of Sugar Hill. The soil is classified as Gleason gravelly sandy loam, an Entic Haploxeroll (U.S. Dep. Agric. Soil Conserv. Serv. 1975) confined principally to the Warner Mountains. Depth to a lithic contact of hard tuff is 40 to 60 inches (102 to 152 cm). The average annual precipitation of 22 inches (559 mm) falls mostly outside the growing season. Site index varies somewhat among plots (*table 1*) but on the average is 50 feet (15 m) at 50 years (Powers and Oliver 1978).

Trees were hand planted to an 8- by 8-foot (2.4- by 2.4-m) spacing in April 1932, 3 years after a wildfire devastated a natural stand of ponderosa pine (*fig. 1*). The site was not prepared except that merchantable killed trees were logged. Stock was 1-I ponderosa and Jeffrey pine grown from seed from an unknown location but probably collected in northeastern California.

Early survival and growth were good for those days (*fig. 1*). After six growing seasons, 80 percent of the ponderosa pines and 66 percent of the Jeffrey pines were surviving. Ponderosa pine had grown to 32 inches (81 cm) and Jeffrey pine to 16 inches (39 cm) in height. By 1959, when thinning began, the plantation was 28 years old, 6 inches (1 S cm) in diameter at breast height

Table 1 —*Stand characteristics (acre basis) after thinning of ponderosa and Jeffrey pines in the Sugar Hill Plantation*

Plot and yea established		Area	Site index (50 yr)	Trees	Growth periods analyzed			Avg. d.b.h.	Avg. height	Basal area	Total[1] volume	Merch [2] volume
					1	2	3					
		Acres	*Feet*			*Years*		*Inches*	*Feet*	*Sq. ft.*	*Cu. ft.*	*Bd. ft.*
I	1959	1.36	55	43	7	4	5	7.4	23	13	103	39
2	1959	2.00	55	81	7	4	5	7.5	23	25	199	58
3	1960	1.00	50	100	6	4	5	6.7	21	24	179	17
4	1961	0.75	45	200	5	4	5	7.8	23	66	539	263
5	1960	1.00	55	300	6	4	5	7.2	21	86	647	154
Control	1960	1.00	45	456	6	5	4	5.5	16	75	436	10

[1] Inside hark from 1-foot stump to tip.
[2] Scribner hoard feet to a 6-inch top inside hark and 8-foot minimum log length: that is.. most trees 9 inches d.b.h.o.b. and larger.

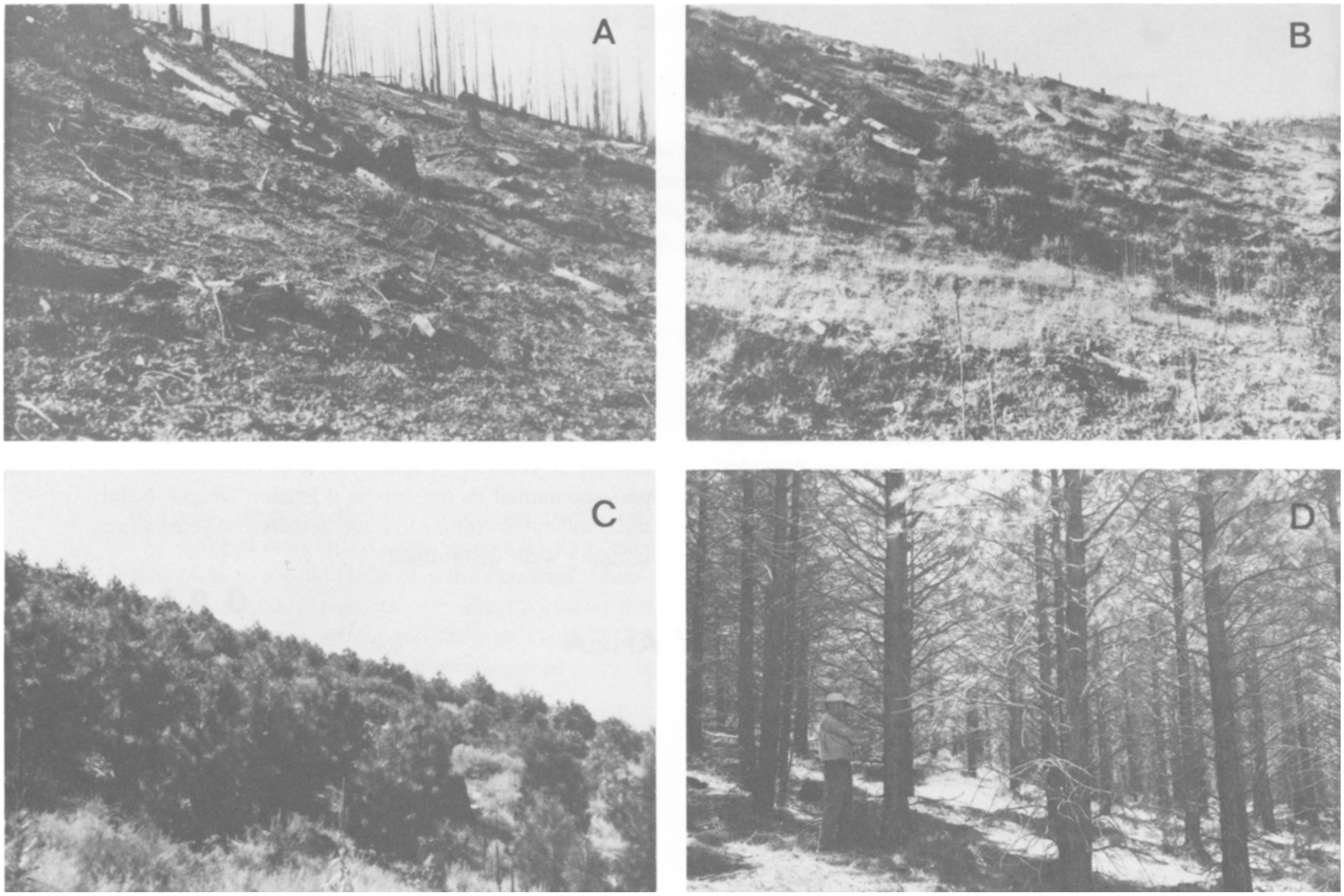

Figure 1—The Sugar Hill Plantation control plot shown (A) in the fall of 1932 after planting; (B) 5 years later in the fall of 1936; (C) at 10 years of age in the fall of 1941; and (D) at 39 years of age in the spring of 1972.

and 18 feet (5 m) tall. All plots contained a scattered understory of rabbitbrush (*Chrysothamnus* sp.), big sagebrush (*Artemisia tridentata* Nutt.) and snowbrush (*Ceanothus velutinus* Dougl. ex Hook.). About 15 years later, brush remained scattered and, in general, inversely proportional to the overstory density.

METHODS

The six plots were thinned to a wide range of stand densities-13 to 86 square feet of basal area per acre (3.0 to 19.7 m^2/ha). Originally, plots varied in size from 1 to 2 acres (0.4 to 0.8 ha). Later, two plots had to be made smaller—plot 1 because it lacked an isolation strip and plot 4 because it was partially destroyed for construction of a fuel break (*table 1*).

All plots were thinned outside the growing season by the usual standard; that is, the most vigorous well-formed dominants and codominants were selected as leave trees, as far as this was compatible with reasonably uniform spacing. Slash was lopped and scattered on all plots. Later, the felled boles were removed from those portions near roads by fuelwood gatherers.

All leave trees were tagged and measured immediately after thinning and remeasured at three intervals of about 5 years thereafter (*table 1*). At each measurement, diameters at breast height for all trees were recorded to the nearest 0.1 inch (0.25 cm) and heights for every fifth tree to the nearest foot (0.3 m).

At the end of the third period, 6 to 10 trees in each plot were chosen so that probabilities were proportional to estimated size for stem volume determinations. Upper stem diameters and lengths were measured with an optical dendrometer. Stem volumes inside bark, in cubic feet and board feet, Scribner, were calculated by Grosenbaugh's (1974) STX computer program as modified by Space (1974).

When these volumes (both cubic and board foot measures) were plotted over the product of diameter squared times total height (D^2H), no differences among volumes of trees in plots thinned to different basal areas could be found. Therefore, the following equations weighted by $1/D^2H$ and solved by least squares were considered adequate for all plots:

$$Vol_T = -0.08123 + 0.00193\ D^2H$$
$$S_{y.x} = 0.0112$$
$$Vol_{BF} = -11.55734 + 0.00734\ D^2H$$
$$S_{y.x} = 0.0910$$

in which

Vol_T = stem volume in cubic feet inside bark from 1-foot (0.3-m) stump to tip
D^2H = d.b.h.^{2} in inches times total height in feet
Vol_{BF} = merchantable stem volume in board feet, Scribner, to a 6-inch (15-cm) top inside bark and a minimum log length of 8 feet (2.4 m)—that is, most trees 9 inches (23 cm) d.b.h.o.b. and larger
$S_{y.x}$ = sample standard deviation from regression

The total height of all trees had to be estimated to calculate plot volumes. Since growth was to be analyzed over three growing periods, a single equation for each plot, expressing height as a function of both diameter and age, was expected to yield more accurate and consistent estimates than individual height/diameter curves would yield for each measurement. Scatter diagrams of height over diameter, combining data for all three periods, were prepared for each plot. A visual inspection of these diagrams suggested that one equation would describe adequately the height/diameter relationship of trees in plots 4 and 5, and the control (thinned to 200 or more trees per acre [494 trees/ha]). And another equation would describe adequately trees in plots 1 , 2, and 3 (thinned to 100 or fewer trees per acre [247 trees/ha]). A multiple regression equation suggested by Curtis (1967) was fitted to each group of plots by a stepwise regression procedure, retaining the most significant terms. The following equations resulted for plots 4 and 5, and the control:

$$H = 1.26695 + 0.34513\ (lnD)\ (lnA) - 0.02136\ (lnD)\ (lnA)2$$
$$S_{y.x} = 0.128$$

and for plots 1, 2, and 3:

$$H = 5.37368 - 0.49461\ (lnD)^2 - 0.50800\ (lnA)^{2.} + 0.24218\ (lnD)\ (lnA)^2$$
$$S_{y.x} = 0.113$$

in which

H = total height in feet
*l*nD = natural logarithm of d.b.h. in inches
*l*nA = natural logarithm of age since planting

Stand characteristics after thinning and after three subsequent growth periods are presented in *table 1* on an acre basis.

GROWTH PATTERNS

Mean annual growth during each of the three periods of about 5 years was analyzed. Periodic annual growth of most tree and stand characteristics was found to be related to stand density and, sometimes, to growth period also (*table 2*).

Diameter

Periodic annual diameter growth was influenced markedly by thinning and the subsequent buildup of stand basal area. Growth was most rapid — 0.5 inch (1.3 cm) per year — during the first period after thinning on the most heavily thinned plot. Growth was slowest — 0.1 inch per year — during the third period in the unthinned control plot. As basal area increased, periodic annual diameter growth decreased at a decreasing rate (*fig. 2A*). This curvilinear relationship was similar for all periods and can be expressed by the equation:

$$PAI\ DBH = 0.82677 - 0.13740\ lnBA$$

in which

PAI DBH = periodic annual increment in diameter in inches
*l*nBA = natural logarithm of basal area in square feet per acre

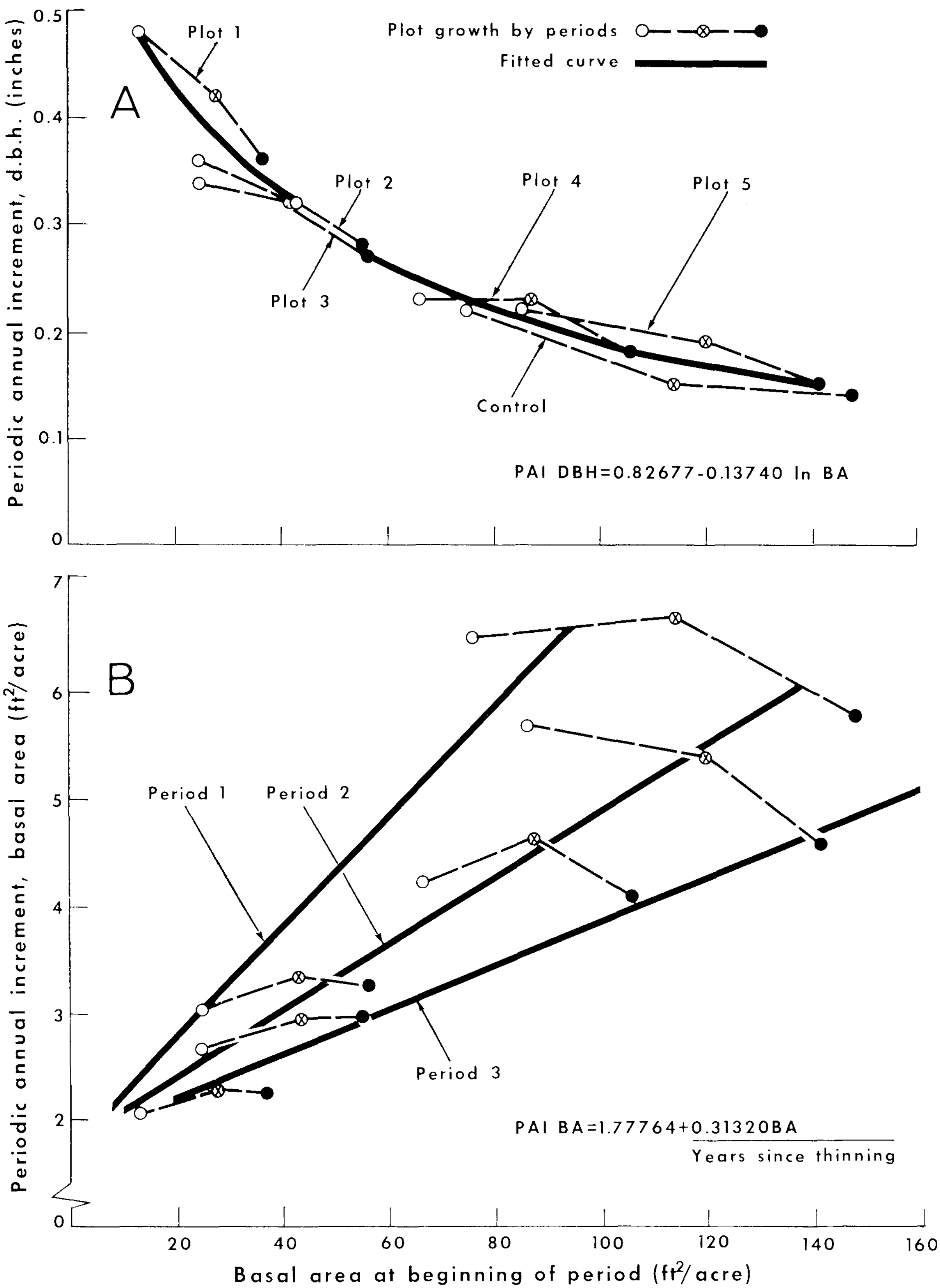

Figure 2—Fifteen years after thinning ponderosa and Jeffrey pine poles in the Sugar Hill Plantation, periodic annual increment (PAI) was determined for each of three periods of about 5 years. (A) The pattern of smaller diameter increment in plots with greater basal area was similar during all periods. (B) Basal area increment was greater with larger stand basal area but less with time since thinning.

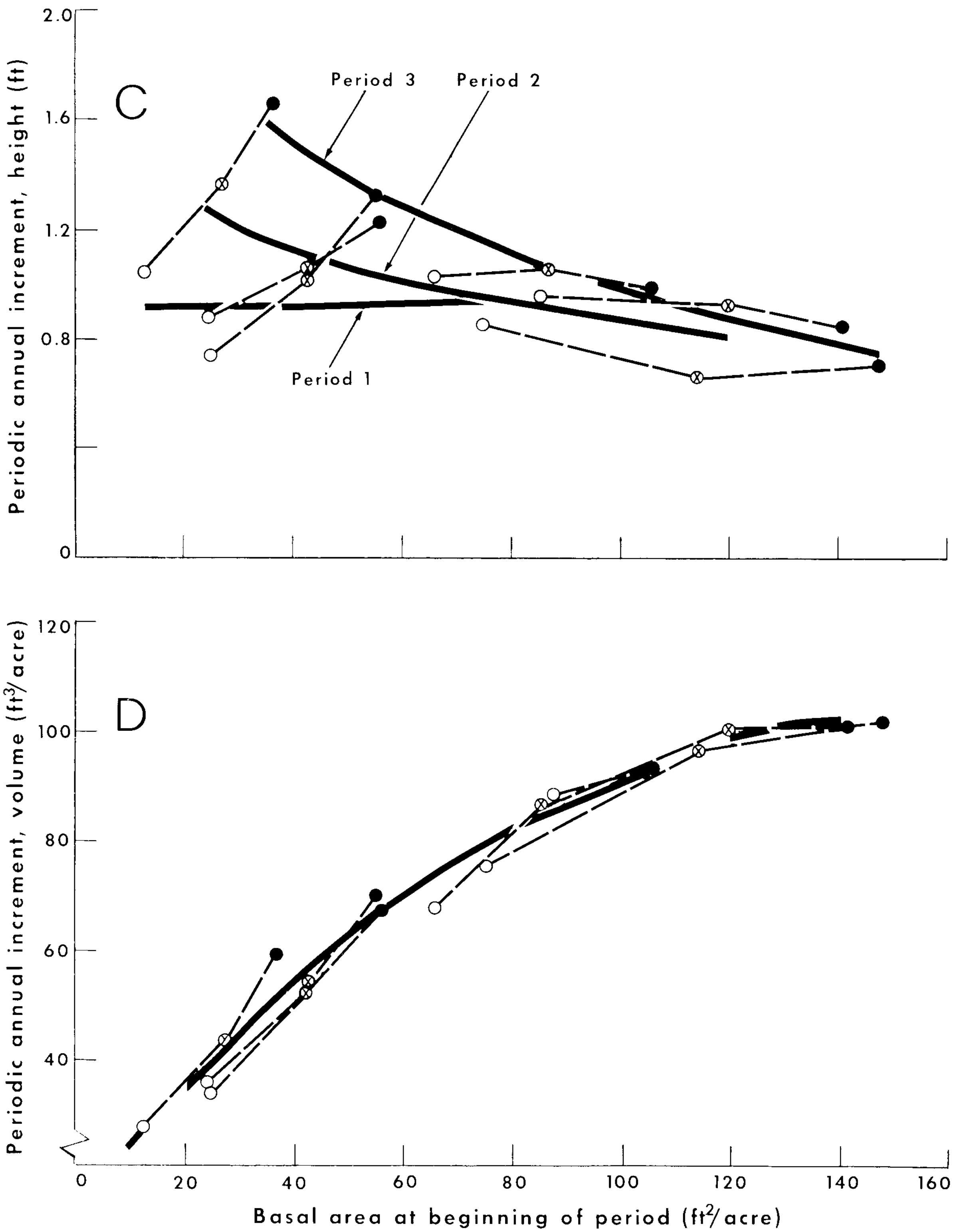

Figure 2 (continued) (C) Height increment was greater in plots with lower basal areas during the second and third periods, only. (D) The pattern of more total volume increment in plots with greater basal area was similar during all periods.

Table 2 — *Periodic annual growth (acre basis) for three growth periods after thinning ponderosa and Jeffrey pine poles in the Sugar Hill Plantation*

Plot	Stand density at beginning of period		Periodic annual growth				
	Trees	Basal area	D.b.h.	Height	Basal area	Total[1] volume	Merch.[1] volume
		Feet[2]	*inches*	*Feet*	*Sq. ft.*	*Cu. ft.*	*Bd. ft.*
			First period				
1	43	13	0.5	1.0	2.0	27	87
2	81	25	.3	0.7	2.6	34	107
3	100	24	.4	0.9	3.0	36	71
4	200	66	.2	1.0	4.2	68	192
5	300	86	.2	1.0	5.7	85	180
Control	456	75	.2	0.8	6.5	76	38
			Second period				
1	43	27	0.4	1.4	2.3	43	164
2	81	43	.3	1.0	2.9	53	199
3	100	43	.3	1.0	3.3	53	184
4	200	87	.2	1.0	4.6	88	316
5	300	120	.2	0.9	5.4	100	348
Control	456	114	.2	0.7	6.7	98	174
			Third period				
1	43	36	0.4	1.7	2.3	59	222
2	81	55	.3	1.3	2.9	70	264
3	100	56	.2	1.2	3.2	68	255
4	200	106	.2	1.0	4.1	94	351
5	299	141	.2	0.8	4.6	101	376
Control	477	147	.1	0.7	5.7	102	289

[1] Inside bark from 1-foot stump to tip.

[2] Scribner board feet to a 6-inch top inside bark and 8-foot minimum log length, that is, most trees 9 inches d.b.h.o.b. and larger.

The influence of basal area is highly significant ($P \leq 0.01$), explaining 95 percent of the variation in periodic annual diameter increment among plots and periods.

By the end of the third growth period or about 15 years after thinning, diameters were distributed as shown in *figure 3*.

Basal Area

Basal area growth was linearly related to stand basal area and differed among growth periods (*fig. 2B*). Periodic annual basal area growth was most rapid for a given stand density during the first period. It ranged from 2.0 square feet per acre (0.46 m^2/ha) in the most heavily thinned plot to 6.5 square feet (1.49 m^2/ha) in the unthinned plot. Basal area growth tended to be less for a given stand density during the second period, but covariance analysis revealed no statistically significant difference.

During the third period, however, basal area growth dropped significantly from that of the second period. The most heavily thinned plot grew 2.3 square feet (0.53 m^2/ha) per year. Basal area growth increased with higher stand densities, reaching 5.7 square feet (1.31 m^2/ha) per year in the unthinned plot.

In general, basal area growth dropped more in succeeding periods in plots unthinned and lightly thinned than it did in plots heavily thinned. These patterns of

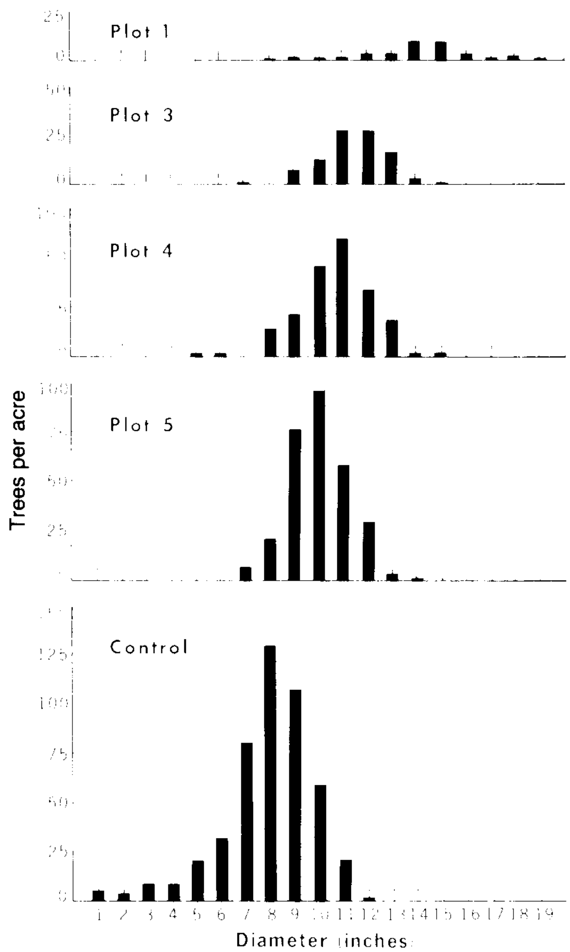

Figure 3—Diameter distributions of plots in the Sugar Hill Plantation 15 years after thinning to five different densities. (Plot 2, not shown, was thinned to about the same density as Plot 3.)

basal area growth following thinning can be combined in the following single expression:

$$\text{PAI BA} = 1.7776 + 0.31320X$$

in which

PAI BA = periodic annual basal area increment in square feet per acre

X = the quotient of stand basal area in square feet per acre at the beginning of the growth period divided by the number of years since thinning

The independent variable explained 79 percent of the variation in basal area growth.

The marked difference among periods in the relation of basal area growth to stand basal area has a possible explanation. The plantation at time of thinning had passed the age when basal area growth is most rapid (Oliver and Powers 1978). On the average, ponderosa pine plantations growing at a density of 370 trees per acre (914 trees per ha) produce 5.4 square feet (1.24 m^2/ha) of basal area annually between the ages of 25 and 30 years on locations having site qualities similar to that of Sugar Hill. Growth drops to 4.8 square feet (1.10 m^2/ha) annually between stand ages of 35 and 40 years. These rates are only slightly lower than those found in the Sugar Hill study for the unthinned and most lightly thinned plots. Trees on these plots grew 6.1 square feet per acre (1.40 m^2/ha) annually between stand ages of 28 and 34, and 5.1 square feet (1.17 m^2/ha) annually between the ages of 38 and 43, on the average.

Height

The relation of periodic annual height growth to stand density following thinning is complex. Height growth response often is delayed 3 or 4 years until the released trees build up their crowns sufficiently to produce the additional food required for increased height growth.

In the Sugar Hill study this delayed response was striking. Height growth over the entire period of about 15 years was not related significantly to post-thinning stand density. But when regressions of periodic annual height growth were calculated for each of the three periods, an increasing response with time since thinning was revealed (*fig. 2C*). No relation between stand basal area and height growth existed during the first period—trees in all plots grew 0.9 foot (0.27 m) per year, on the average. During the second period, trees in the three plots most heavily thinned grew faster in height—up to 1.4 feet (0.43 per year—whereas height growth in the unthinned and two lightly thinned plots dropped slightly. This trend, though evident, was not statistically significant. During the last period, however, height growth was significantly related to stand basal area. Growth rate of trees in the three heavily thinned plots continued to increase, up to 1.7 feet (0.52 m) per year. Growth rate of trees in the unthinned plots and in the two lightly thinned plots declined again—this time to 0.8 foot (0.24 m) per year.

This delay in height growth response to thinning can be inferred from reports of other thinning studies in ponderosa pine. Barrett (1963, 1968) found no significant response from thinning studies in pole-size ponderosa pine on comparable sites in the Pacific Northwest; neither did Schubert (1971), reporting on a thinning study in pole-size ponderosa pine on a slightly poorer site in northern Arizona. These three reports were based on the first 5 or 6 years following thinning of dense natural stands. When height growth has been followed for longer periods, most investigators report a marked response (Stage 1958; Myers 1958; Boldt 1970).

Volume

Cubic Volume

Periodic annual cubic volume growth was closely related to stand basal area during each of the three periods. When each period was analyzed separately, the relationships were positive and linear; the rate of increase in volume growth with increasing basal area slowed with each succeeding period. Only when all periods were combined for analysis (18 observations) did a full picture of the relation between stand density and cubic volume production emerge (*fig. 2D*). The relationship is similar for all three periods and departs significantly from linearity.

Volume production increased almost linearly with accumulating basal area to about 76 cubic feet per acre (5.32 m^3/ha) at 70 square feet of basal area per acre (16.1 m^2/ha). The rate of increase began to slacken at higher stand basal areas, reaching about 97 cubic feet per acre (6.79 m^3/ha) annually at 110 square feet per acre (25.2 m^2/ha). Cubic volume production remained virtually static at basal areas above 110 square feet per acre (25.2 m^2/ha). This stand density was optimum for timber production in this plantation since it represented nearly the maximum volume production on the minimum amount of growing stock.

The relation of cubic volume production to stand basal area is described best by the quadratic equation:

$$\text{PAI Vol} = 11.47631 + 1.20045X - 0.00396X^2$$
$$S_{y.x} = 3.705$$

in which

PAI Vol = periodic annual volume increment in cubic feet per acre
X = basal area in square feet per acre

Basal area explains 97 percent of the variation in cubic volume production in all plots over the period of about 15 years following thinning.

Although the curve for the quadratic equation (*fig. 2D*) fits best within the range of data, extrapolating growth to higher basal areas may create errors. The equation implies a drop in volume production above basal areas of 152 square feet per acre (34.9 m^2/ha), but actual production may remain constant before dropping at a much higher basal area.

This estimate of volume production is 20 percent higher for plots lightly thinned than that reported earlier (Oliver 1972) after two growth periods. The earlier report included six plots in natural stands subsequently found to be on sites of lower productivity. Their inclusion caused volume production to be underestimated at Sugar Hill.

Board Feet

Standing merchantable volume built up rapidly on all plots during the 15 years. Ingrowth into merchantable sizes was the major contributor during the first period in all plots, and then declined in importance. Only in the unthinned plot during the third period was ingrowth important still.

At time of thinning, when the stand was about 28 years old, merchantable volume production was just beginning (*table 1*). Only a few trees had reached the merchantable size of 9 inches d.b.h.o.b. (capable of producing an 8-foot log 6 inches in diameter inside bark at the small end—intensive utilization by today's standard). For example, the unthinned plot contained only 10 board feet per acre. Merchantable volume was highest (263 bd. ft/acre) in the plot thinned to 66 square feet of basal area per acre (15.2 m^2/ha) because this plot contained trees with the largest average diameter after thinning.

Merchantable volume production was related to stand basal area within periods but differed markedly among periods because of differing tree size (*table 2*). Within periods, board-foot production was highest in moderately thinned plots. In the unthinned plot, it dropped to about the level of plots heavily thinned.

Board-foot production was highest at a constant stand density during each period only when density was expressed as number of trees per acre rather than basal area. At 200 to 300 trees per acre (494 to 741 trees/ha) production reached 192 board feet per acre during the first period. Highest production level was 348 board feet during the second period and only slightly more, 376 board feet, during the third period, as ingrowth became inconsequential.

Fortunately, the stand density optimum for cubic volume production seems to be about optimum for board-foot production, also. At the beginning of the third period of growth, 200 to 300 trees per acre (494 to 741 trees/ha) produced 106 to 141 square feet of basal area per acre (24.3 to 32.3 m^2/ha). Optimum basal area for cubic volume production was estimated to be 110 square feet (25.2 m^2/ha).

CONCLUSIONS

The 15-year growth record after precommercial thinning of plots in the Sugar Hill Plantation provides an opportunity to evaluate a common thinning practice. Ponderosa and Jeffrey pine plantations usually are precommercially thinned once in the sapling or small pole-size classes to minimize cost, fire hazard, and growth loss from intertree competition until they reach merchantable size.

Thinning intensity is governed, primarily, by the manager's estimate of minimum merchantable size and minimum volume per acre that can be removed in a commercial thinning at some future date. Commercial low thinnings removing 1000 board feet per acre of trees 9 to 12 inches (22.9 to 30.5 cm) in diameter would seem to be profitable and common in the near future. Similar thinnings occasionally are being sold today under ideal conditions.

Optimum stocking levels and resulting stand performance can be predicted from the economic forecasts and thinning plot results. I estimate that 25 years will be required for the Sugar Hill Plantation to reach 12 inches in average stand diameter (yielding trees 9 to 12 inches in a low thinning) when thinned at 7 inches (17.8 cm) to a basal area of 50 square feet per acre (11.5 m^2/ha) or 160 trees per acre (395 trees /ha). Thus, at age 53, the plantation can be expected to have the following distribution of diameters on an acre:

D.b.h.:

Inches	Cm	*Trees*
8	20	2
9	23	6
10	25	15
11	28	30
12	30	47
13	33	33
14	36	20
15	38	6
16	41	1

Other characteristics would he as follows:

Basal area per acre:	126 square feet (28.9 m^2/ha)
Total volume per acre:	1800 cubic feet (125.9 m^3/ha)
Merchantable volume per acre:	5300 board feet

A commercial thinning from below seems feasible at age 53 if we assume: (a) 110 square feet per acre (25.2 m^2/ha) as optimum leave stand density, (b) annual growth of 3.5 square feet of basal area per acre (0.80 m^2/ha), and (c) a commercial thinning cycle of 10 years. A low thinning would remove 34 square feet per acre (7.8 m^2/ha) leaving 92 square feet of basal area per acre (21.1 m^2/ha)—an optimum density for continued volume production on a 10-year thinning cycle. About 1200 board feet of merchantable material per acre might thus be produced. These yields are similar to those predicted for natural stands of ponderosa pine on similar sites in the Pacific Northwest, where one thinning left the stand with an average diameter of 6 inches (Sassaman and others 1977).

Precommercial thinning of pole-size plantations as was done here is not recommended. One of the disadvantages stated previously is growth loss from intertree competition. If the Sugar Hill Plantation had been thinned as saplings to 160 trees per acre,-merchantable size might have been reached 10 years sooner than age 53.

These growth projections are based upon one stand only. Specific growth rates may differ in other stands but the general relationships should be similar.

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Growth was analyzed after one thinning in a plantation of pole-size ponderosa and Jeffrey pines on land having a site index of 50 feet at 50 years. Periodic annual increment was determined for each of three 5-year periods. On this basis, increment in diameter and cubic volume were found to he related closely to stand basal area only. Basal area and height increment, however, were also related to time since thinning: basal area growth decreased and height growth increased with each succeeding period. The optimum basal area for volume production (both cubic and board-foot measures) was estimated to be 110 ft^2/acre. Optimum stocking levels and resulting stand performance are predicted for a common thinning practice.

Retrieval Terms: Pinus ponderosa, Pinus jeffreyi, thinning response, diameter growth, basal area, increment, stocking level, plantations, Modoc National Forest.

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