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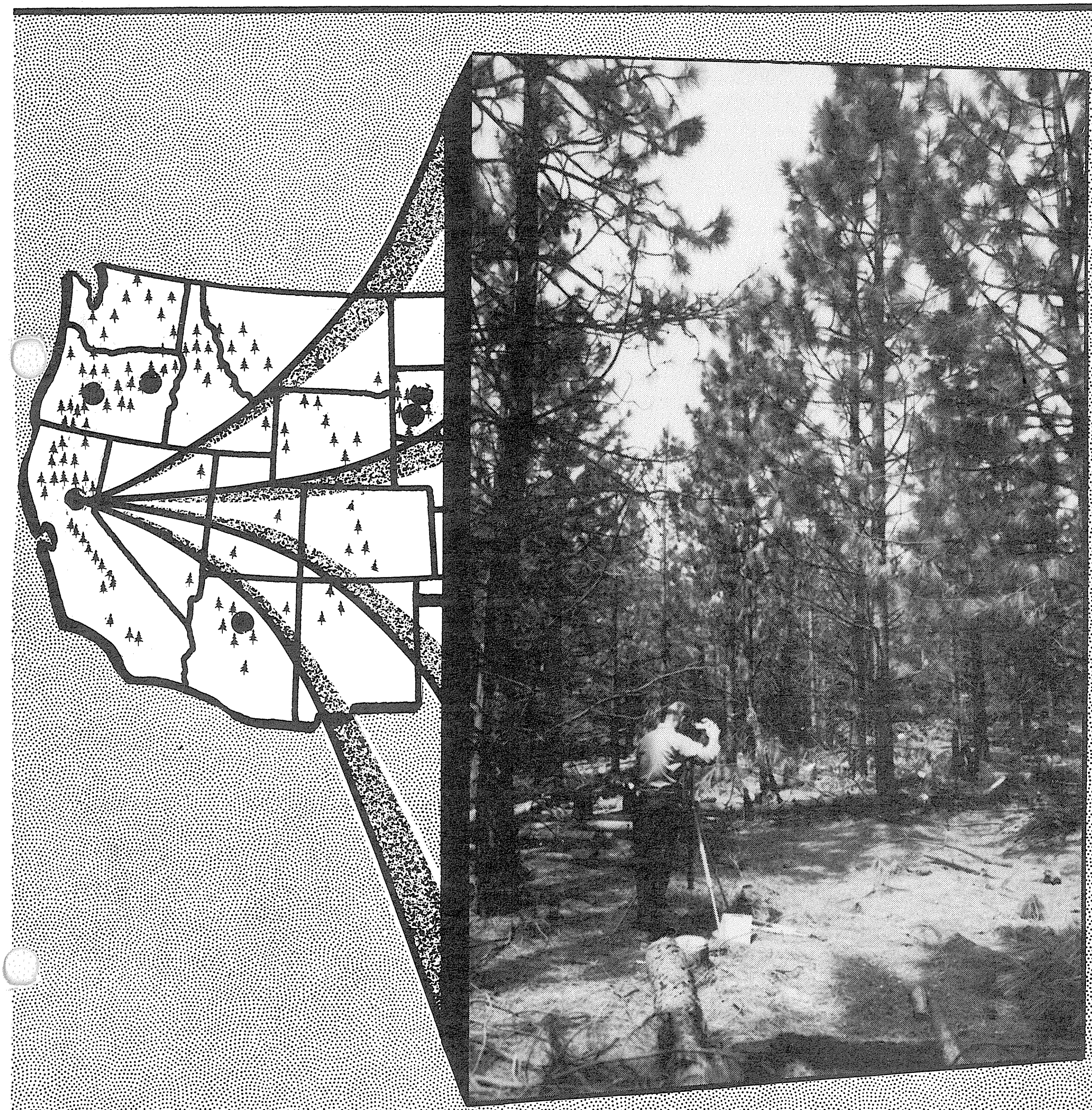
Growth of Planted Ponderosa Pine Thinned to Different Stocking Levels in Northern California

William W. Oliver



The Author

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Cover: Growing-stock levels of ponderosa pine are being studied in four states: Cascade Range and Blue Mountains of Oregon, Black Hills of South Dakota, Colorado River Plateau of Arizona, and Sierra Nevada of California.

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CONTENTS

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PREFACE

Growth of the most widely distributed pine in North America is under joint study by the western Forest and Range Experiment Stations of the Forest Service, U.S. Department of Agriculture. This west-wide study of growing-stock levels in even-aged ponderosa pine is in response to increasing demands for better and more precise estimates of yields possible in intensively managed stands.

This paper reports 5-year results from one installation in a plantation on the west slope of the Sierra Nevada of California. Reports from installations in naturally regenerated stands—two each in the Black Hills of South Dakota and central Oregon and one in northern Arizona—will be issued periodically, followed by a report summarizing results from all six installations.

Previous publications on this study are:

Myers, Clifford A.
1967. **Growing stock levels in even-aged ponderosa pine.** U.S. Forest Serv. Res. Paper RM-33, 8 p., illus. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.

Schubert, Gilbert H.
1971. **Growth response of even-aged ponderosa pines related to stand density levels.** J. For. 69 (12):857-860, illus.

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1974. **Silviculture of southwestern ponderosa pine: The status of our knowledge.** USDA Forest Serv. Res. Paper RM-123, 71 p., illus. Rocky Mtn. Forest and Range Exp. Stn., Fort Collins, Colo.

Schubert, Gilbert H.
1976. **Silvicultural practices for intensified forest management.** In **Trees—The renewable resource. Proc. Rocky Mtn. For. Ind. Conf.** [Tucson, Ariz., March, 1976], p. 37-54.

Severson, Kieth E., and Charles E. Boldt.
1977. **Options for Black Hills forest owners: timber, forage, or both.** Rangeman's J. 4(1):13-15, illus.

IN BRIEF

Oliver, William W.

1979. **Growth of planted ponderosa pine thinned to different stocking levels in northern California.** Res. Paper PSW-147, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Retrieval Terms: Pinus ponderosa, stand density-growth, diameter growth, basal area growth, volume growth, stocking level, plantation, California.

In California, most of the highly productive ponderosa pine (*Pinus ponderosa* Laws.) stands are found in plantations at mid-elevations on the west slopes of the Sierra Nevada and Cascade Ranges. But growth rates and their relationship to stand density are less known for these high sites than they are for less productive sites to the east. This paper reports remarkable growth for 5 years after thinning ponderosa pine in the Elliot Ranch Plantation to a wide range of stocking levels on a productive site.

The plantation lies at 4000 feet (1220 m) elevation, 11 miles (18 km) northeast of Foresthill, Placer County, California. Abundant precipitation (60 inches or 1524 mm annually), mild temperatures, and deep clay-loam soils provide favorable growing conditions. The Site Index is estimated to be 115 feet (35 m) at 50 years (Powers and Oliver 1978).

In spring 1950, following a wildfire the previous year that burned a brush and snag field, ponderosa pine was hand-planted at a 6- by 8-foot (1.8- by 2.4-m) spacing. Deerbrush (*Ceanothus integerrimus* H. and A.) germinated abundantly, but was held in check by cattle browsing. By 1969, when the study began, the plantation completely dominated the deerbrush understory.

Five growing-stock levels (GSL's) are being tested—40, 70, 100, 130, and 160. The GSL's are the basal areas in square feet per acre that the stand has, or will have, after thinning when the stand diameter averages 10 inches (25.4 cm) or more (Myers 1967). Treatments were replicated three times and assigned at random to 15 one-half acre (0.2 ha) plots. Trees were marked and the plots precommercially thinned in late 1969 when the plantation was 20 years old. Trees were measured the following spring before growth began and remeasured after five growing seasons.

Periodic annual growth in diameter was influenced strongly by growing stock level. Trees in plots heavily thinned to GSL 40 grew most rapidly at the annual rate of 0.51 inch (1.3 cm). Annual diameter growth declined rapidly with increasing stand density, then decreased to an annual rate of 0.21 inch (0.5 cm) for trees in plots lightly thinned to GSL 160. Surprisingly, only trees in plots heavily thinned to GSL 40 (and briefly in GSL 70) grew faster in diameter after thinning than these same trees grew before thinning. Trees in less heavily thinned plots continued their pattern of slackening diameter growth, begun before thinning.

Basal area growth was linearly related to stand density. Tree growth was 4.7 square feet per acre (1.1 m^2/ha) annually for GSL 40, increasing to 9.0 square feet per acre (2.1 m^2/ha) annually for GSL 160.

Overall, the average tree grew 1.9 feet (0.6 m) annually in height during the 5 years since thinning. Trees in plots at higher GSL's tended to grow more slowly than trees at lower GSL's, but differences were not significant.

Tree crowns were long (live crown ratio of 70 percent) when the plantation was thinned. Since thinning, all live crown ratios have decreased, especially at higher stand densities.

Total stem volume production from ground line to tip was impressive in these fully crowned trees. Volume production rose steadily with increasing growing stock levels from 116 cubic feet per acre (8.1 m^3/ha) for GSL 40 to 255 cubic feet per acre (17.8 m^3/ha) for GSL 160. In terms of compound interest, production ranged from 14 percent for GSL 40 to 10 percent for GSL 160.

Tree damage and mortality have been minor influences on stand growth. The most important agent—a heavy, wet snowfall in the winter of 1970

—broke or bent stems, killing 1.9 percent and damaging 9.4 percent of all trees in the study.

Volume production of 255 cubic feet per acre may seem unusually high, but it is about that predicted for similar stands (Meyer 1938, Oliver and Powers 1978). Furthermore, young plantations often grow faster than comparable natural stands because competition among trees and with other vegetation is reduced.

Although not tested, unthinned plots probably would have produced more stemwood than the 255 cubic feet grown by the GSL 160 plots. If so, what advantages does thinning create for this or similar pole-sized plantations if potential volume production is lost? Thinning offers several advantages, including shortened time to reach merchantable size by an estimated 15 years, and reduced risk of tree mortality from inter-tree competition and bark beetle attack by improving tree vigor. Also, in today's sawtimber market, poles have little value, reducing the importance of immediate growth loss.

Precommercial thinning of pole-sized plantations, as done here, is not recommended. Thinning usually reduces costs and slash volumes to acceptable levels when, instead, plantations are sapling-sized.

Stand density-growth relationships are becoming well-defined for young, even-aged stands of ponderosa pine (*Pinus ponderosa* Laws.) on sites of medium to low productivity east of the Sierra Nevada and Cascade Ranges. Until recently, thinning efforts in California were concentrated east of these ranges because dense stands often stagnate in diameter and height growth.

Most highly productive ponderosa pines, however, are found in plantations at mid-elevations on the west slopes of the Sierra Nevada and Cascade Ranges in California. Dense stands seldom stagnate on these high-quality sites, but growth rates are slowed markedly. Plantations often are thinned precommercially to concentrate growth on potential crop trees and shorten the time until they can yield a marketable product. Growth rates and their relationship to stand density are known poorly for these productive westside sites. And stocking recommendations to meet management objectives are based on few research results.

This paper reports the remarkable growth of a ponderosa pine plantation on a highly productive site 5 years after thinning to a wide range of growing stock levels.

THE ELLIOT RANCH PLANTATION

Five growing stock levels are being tested in the Elliot Ranch Plantation, 11 miles (18 km) northeast of Foresthill, Placer County, California. This plantation lies at an elevation of 4000 feet (1220 m) on the west slope of the northern Sierra Nevada (lat. 39° 8′ N, long. 120° 45′ W). Plots are within a 20-acre (8-ha) area on a gentle, south-facing slope.

Average annual precipitation since the plantation was established is estimated to be 60 inches (1524 mm), only 9 percent of which falls during the April through September growing season. Temperatures are mild, varying between daily means of 72°F (22°C) in July and August and 38°F (3°C) in January.

Three clay-loam soils underlie the study area. The Cohasset Series occupies half the area. Cohasset is an Ultic Haploxeralf (U.S. Dep. Agric. Soil Conserv. Serv. 1975) overlying the Mehrten Formation, a Pliocene Epoch tuff breccia. One third is underlaid with the Horseshoe Series, a Xeric Haplohumult developed from Tertiary Period river gravels. An alluvial soil, unclassified by series, is the third soil present. Depth to parent material of all three soils is at least 5 feet (1.5 m).

The average site index is estimated to be 115 feet (35.1 m) at 50 years (Powers and Oliver 1978). Cohasset clay-loam is slightly more productive than Horseshoe and, on the study area, trees growing in Cohasset soil are estimated to be 120 feet (36.6 m) tall at 50 years. In contrast, trees growing on Horseshoe soil are estimated to reach 115 feet (35.1 m) at 50 years. Site index of the alluvial soil seems similar in productivity to Horseshoe Series.

The original cover of old-growth mixed conifers was burned in 1936. Plantings were made in portions of the area in the 4 years following, but were unsuccessful probably because rapidly invading deerbrush (*Ceanothus integerrimus* H. and A.) formed a dense brushfield. In September 1949, this brush and snag field was destroyed by another fire.

The area, now known as the Elliot Ranch Plantation, was planted in spring 1950 with 1-1 ponderosa pine stock from the appropriate seed zone. Trees were hand planted at a 6- by 8-foot (1.8- by 2.4-m) spacing in the ashes within which deerbrush seeds were germinating abundantly.

During the early years of the Elliot Ranch Plantation, the Tahoe National Forest evaluated cattle browsing as a method of controlling deerbrush (Sindel 1963). In the first year, before management procedures were perfected, cattle browsed over 90 percent of the pines, but few were killed. Since then, cattle use has remained heavy; but by removing cattle by September 15 each year, cattle have ignored the trees while browsing heavily on deerbrush.

Another fire, in August 1960, devastated 45,000 acres (18,225 ha) completely surrounding the Elliot Ranch Plantation. Small spot fires, less than 50 feet (15 m) in diameter and originating from burning snags, killed or scarred a few plantation trees. The plantation otherwise escaped unharmed.

By 1969, when the study began, trees completely dominated the deerbrush understory. Basal area averaged 155 square feet per acre (35 m^2/ha) and occasionally exceeded 300 square feet per acre (69 m^2/ha). The average tree was 7.0 inches (17.8 cm) d.b.h. *(table 1)* and 33 feet (10.1 m) tall.

Table 1—*Stand characteristics per acre before thinning a 20-year-old ponderosa pine plantation on a productive site to five growing stock levels*

Growing stock level[1]	Plot no.	Total trees	Average d.b.h.	Basal area
			Inches	*Sq. ft.*
40	13	487	8.2	177
	10	836	6.3	182
	8	719	6.5	165
70	15	486	7.4	147
	7	592	7.0	160
	5	509	7.2	143
100	14	426	7.7	138
	6	582	6.9	150
	1	493	7.0	133
130	11	509	8.0	178
	4	576	6.9	149
	2	533	6.5	122
160	12	620	7.0	164
	9	814	5.8	151
	3	583	7.1	160

[1]Stand density expressed as the basal area per acre that will remain after thinning when average stand diameter is 10 inches or more.

METHODS

The Elliot Ranch Plantation is part of a west-wide growing-stock-levels study in even-aged ponderosa pine (Myers 1967). From a common study plan, each installation evaluates growth response to thinning in stand sizes growing on site qualities common to each region. Each installation is scheduled to run for 20 years, with measurements at 5-year intervals.

At Elliot Ranch, the five growing stock levels (GSL's) under test are 40, 70, 100, 130, and 160 *(fig. 1)*. These GSL's are the basal areas in square feet per acre that the stand has—or will have—after thinning, when the stand diameter averages 10 inches (25.4 cm) or more. The actual basal area after thinning stands less than 10 inches can be determined from *figure 2*. Each growing stock level was replicated three times. Treatments were assigned at random to 15 one-half acre (0.2 ha) plots. Trees were marked and the plots precommercially thinned in fall and winter 1969 when the plantation was 20 years old.

Thinning this stand of large poles precommercially generated huge volumes of slash. In plots heavily thinned to GSL's 40, 70, and 100, slash was eliminated to lessen fire hazard and reduce chances of insect attack. Tops and limbs of all felled trees were piled and burned, often within the plots. Where slash volumes were light (GSL's 130 and 160), slash was lopped and scattered. Tree boles in every plot were bucked into 6- to 8-foot (1.8- to 2.4-m) lengths; in the following fall, those easily accessible were removed by fuelwood gatherers.

Before growth began in the following spring, all trees were tagged, were described by crown class, and were measured for d.b.h. to the nearest 0.1 inch (0.25 cm). Tree damage and diseases were noted. Also, 20 percent of the trees, randomly chosen in each plot, were measured to the nearest foot (0.3 m) for total height, crown width, and crown length. Stem volumes were measured on six trees per plot. Selection probability for this sample was proportional to estimated cubic volume. Upper stem diameters and lengths were measured by an optical dendrometer.

All measurements were repeated on the same trees after five growing seasons *(fig. 3)*. Increment cores also were extracted from 8 percent, or not less than five trees, randomly selected in each plot, for estimating annual diameter growth. Ring widths were measured back to 1965 to determine diameter

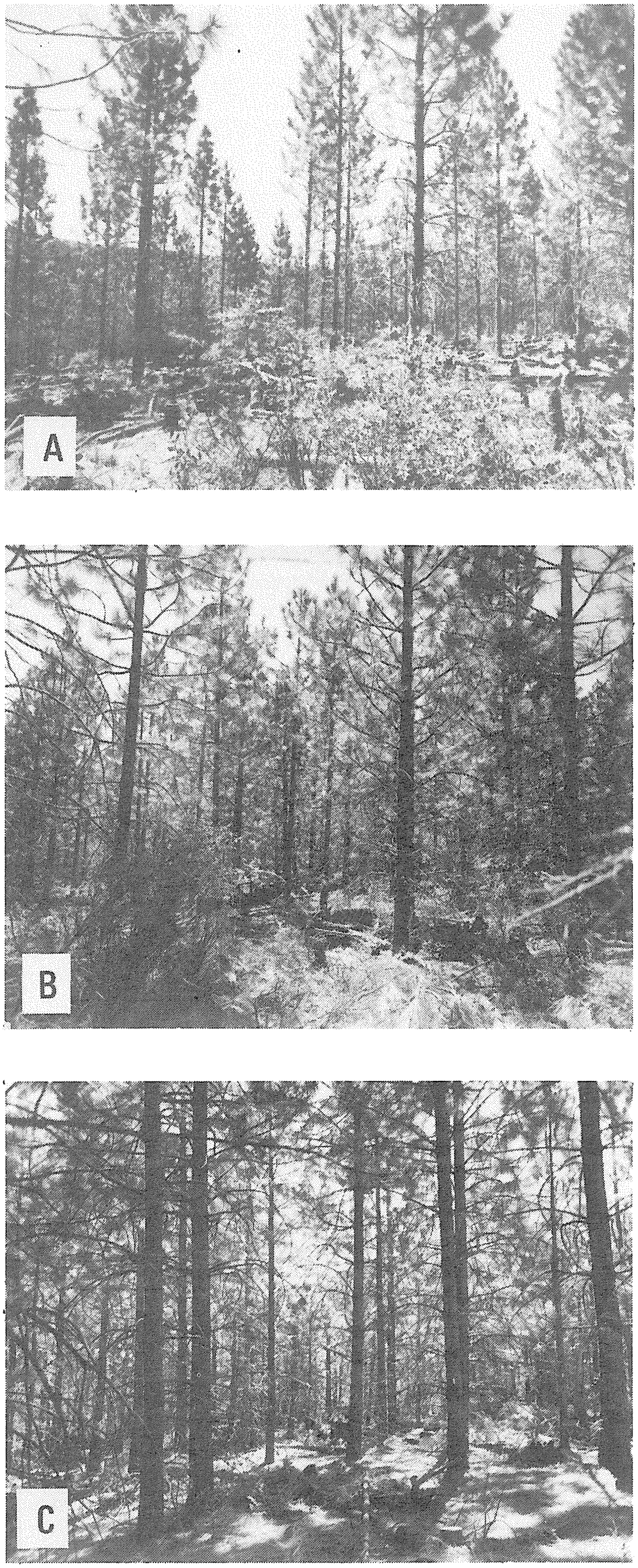

Figure 1—The Elliot Ranch Plantation was thinned at 20 years of age to five different growing stock levels (GSL), including *(A)* GSL 40, *(B)* GSL 100, and *(C)* GSL 160.

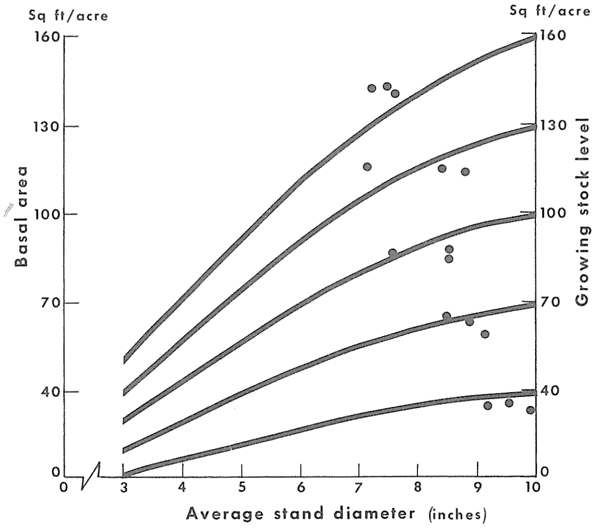

Figure 2—Basal area after thinning in relation to average stand diameter. The growing stock levels for ponderosa pine are standard (Myers 1967).

growth rate for the 5 years preceding thinning.

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). Plot volumes immediately after thinning and five growing seasons later were obtained by the following equations.[1]

After thinning:

$$V = \frac{K}{n} \sum_{i=1}^{n} \frac{V_i}{est_i}$$

Five years later:

$$V = \frac{K}{n_5} \sum_{i=1}^{n_5} \frac{V_{i5}}{est_i}$$

in which
V = plot volume in cubic feet
K = total estimated plot volume in cubic feet immediately after thinning
n = number of dendrometered trees immediately after thinning
n_5 = number of dendrometered trees living 5 years later
V_i = volume measured by dendrometer of $tree_i$
est_i = estimated cubic volume of $tree_i$
V_{i5} = volume measured by dendrometer of living $tree_i$ 5 years later.

Stand characteristics immediately after thinning and 5 years later are presented on an acre basis in *table 2.*

GROWTH RELATED TO STOCKING LEVEL

Diameter

Periodic annual growth in diameter was influenced strongly by growing stock level. Trees in plots heavily thinned to GSL 40 grew most rapidly at the annual rate of 0.51 inch (1.3 cm) *(table 3).* At first, annual diameter growth declined rapidly with increasing stand density, then decreased to a rate of 0.21 inch (0.5 cm) annually for trees in plots lightly thinned to GSL 160 *(fig. 4).* Trees at GSL 40 and GSL 70 grew in diameter at rates significantly ($P \leqslant 0.05$) different from each other and all other stand densities. At higher stand densities, only trees at nonadjacent GSL's differed significantly because growth rate changes were small.

The largest trees in each plot also were influenced by stand density, but to a lesser extent than the average tree *(table 3).* Diameter growth rate of the 50 largest trees per acre (124 largest trees per ha) declined 37 percent compared to 59 percent for all trees when stand density increased from GSL 40 to GSL 160.

How does annual diameter growth of the leave trees after thinning compare with that before thinning? Nearly all trees were declining in growth rate at the time of thinning and, surprisingly, most growing stock levels did not halt that decline *(fig. 5).* Overall, the average leave tree grew 0.41 inch (1.0 cm) annually for the 5-year period before thinning. In the first year after thinning, only trees in plots heavily thinned to GSL 40 and GSL 70 grew more than before. Trees at higher stand densities grew at the same, or slower, rate than during the 5-years before thinning. Diameter growth rates for the second and third years continued to rise only in trees most heavily thinned (GSL 40). Trees at GSL 70 slowed in diameter growth to their pre-thinning rate. Trees at higher stand densities continued to decline.

[1]Personal communication, Nancy X. Norick and David A. Sharpnack, Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif., January 28, 1970.

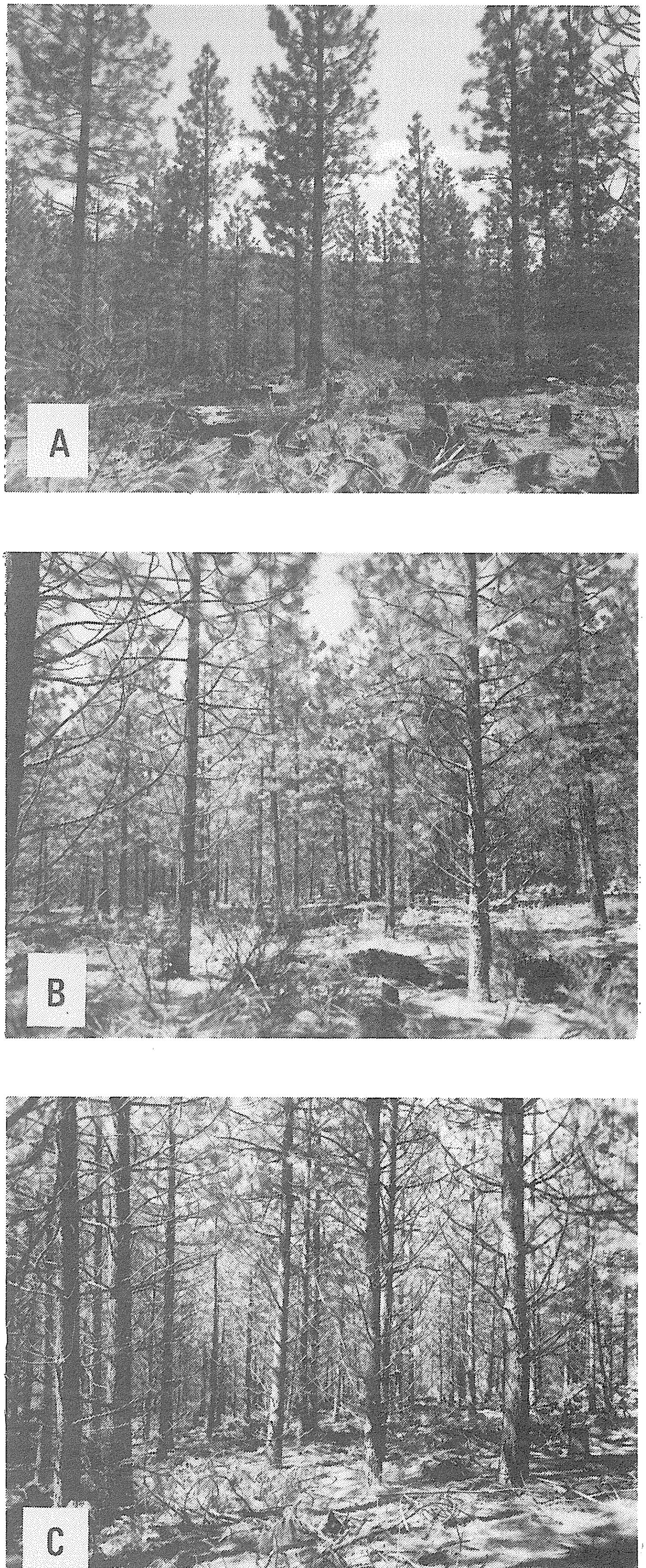

Figure 3—Five years after thinning the Elliot Ranch Plantation to growing stock levels of 40 *(A)*, 100 *(B)*, and 160 *(C)*.

Diameter growth for all growing stock levels during the fourth year (1973) fell to only two-thirds of that for the year before. The reason for this drastic drop in diameter growth is unclear. However, spring 1973 was unusually dry in the Sierra Nevada. After March 1, one-third less than normal rain fell, only about 1 inch (2.5 cm) of which fell after the start of the growing season. Noticeably reduced growth from drought seems unlikely, however, because total winter rainfall was sufficient to recharge the soil, and because the water-holding capacity of this soil is large.

More likely, reduced growth was caused by the severe cold that gripped northern California for 5 days in December 1972. Minimum temperatures at Elliot Ranch, as estimated from neighboring weather stations, probably dropped as low as 5 °F (− 15 °C). Outwardly, the trees appeared unaffected when examined the following summer, thus ruling out winter desiccation—a common result of the cold wave seen elsewhere. Whatever the cause, diameter growth of ponderosa pine in 1973 was reduced in many areas on the westside of the Sierra Nevada.

Trees at all growing stock levels recovered in the fifth year to grow at a rate only slightly less than that of the third year. Over the 5-year period, only trees on plots heavily thinned to GSL 40 grew faster after thinning than before. Trees at GSL 70 grew about as fast as before thinning, and trees at all higher stand densities grew substantially less in rate of diameter growth after thinning.

Table 2—*Stand characteristics per acre after thinning a 20-year-old ponderosa pine plantation on a productive site to five growing stock levels and 5 years later*

Growing stock levels[1]	Plot no.	Total trees	D.b.h.	Height	Crown dimensions: Length	Crown dimensions: Width	Crown dimensions: Live crown	Basal area	Net Volume: Total[2]	Net Volume: Merch.[3]	Mortality
			Inches	*Feet*	*Feet*	*Feet*	*Percent*	*Sq. ft.*	*Cu. ft.*	*Bd. ft.*	*Cu. ft.*
					After thinning						
40	13	68	10.0	45	31	12	69	37	635	1620	
	10	84	9.1	40	27	12	66	38	624	789	
	8	80	9.5	40	29	12	72	39	579	1082	
70	15	144	9.0	44	31	12	70	63	1108	1673	
	7	156	8.7	37	26	11	71	64	1037	1435	
	5	174	8.3	35	26	11	74	65	960	0	
100	14	227	8.6	39	28	11	71	92	1568	1437	
	6	212	8.6	40	28	11	72	86	1226	1567	
	1	287	7.5	30	22	10	74	89	1277	576	
130	11	277	8.8	45	30	12	67	116	1907	909	
	4	322	8.2	37	26	11	71	118	1832	485	
	2	439	7.0	31	22	10	71	118	1871	408	
160	12	476	7.4	35	23	10	68	143	2195	1652	
	9	548	7.0	28	19	9	68	144	1886	1360	
	3	493	7.3	35	24	10	70	145	2033	1833	
					5 Years later						
40	13	68	12.6	58	36	17	62	59	1139	3403	0
	10	80	11.6	54	35	16	66	62	1245	3188	17
	8	78	12.1	50	34	18	69	64	1194	3144	5
70	15	142	10.8	54	36	17	67	92	1899	4429	7
	7	154	10.8	49	31	15	63	98	1863	4314	12
	5	172	10.1	43	28	15	66	96	1771	2389	5
100	14	219	10.2	50	31	15	63	128	2469	4856	48
	6	202	10.1	48	30	14	63	118	1957	3520	51
	1	283	8.8	37	24	13	66	122	2156	1667	17
130	11	269	10.2	56	34	16	60	159	3037	4684	36
	4	320	9.4	44	26	14	59	156	2704	2654	7
	2	425	8.1	38	21	12	57	157	2892	4049	31
160	12	458	8.6	44	24	13	56	193	3279	5663	71
	9	532	7.9	37	20	11	56	189	3276	3595	30
	3	485	8.3	43	25	12	58	185	3390	3019	24

[1]Stand density expressed as the basal area per acre that will remain after thinning when average stand diameter is 10 inches or more.
[2]Gross volume inside bark from ground line to tip less mortality.
[3]Scribner board feet to a 6-inch top inside bark and an 8-foot minimum log length, i.e., most trees 9 inches d.b.h.o.b. and larger.

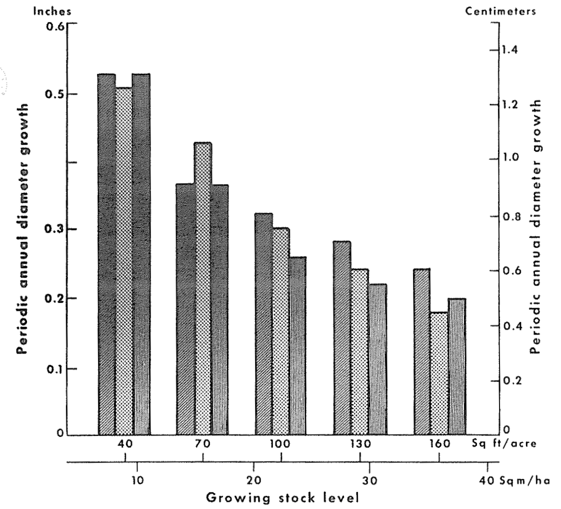

Figure 4— Diameter growth slowed with increasing levels of growing stock for 5 years after thinning a plantation of ponderosa pine poles on a productive site.

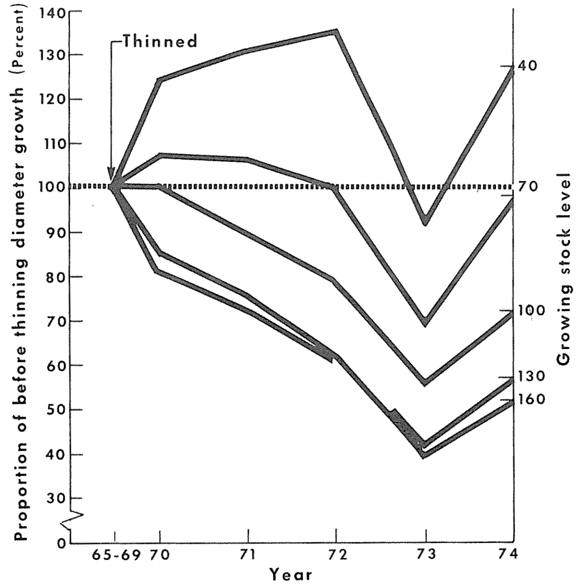

Figure 5— Only heavy thinning to growing stock level 70 or below increased diameter growth of leave trees in a plantation of ponderosa pine poles on a productive site.

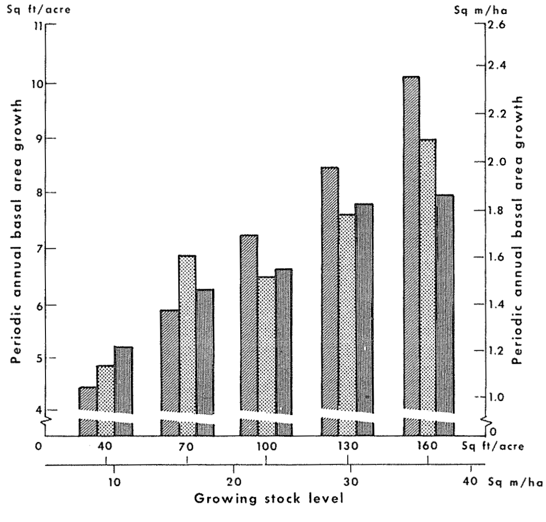

Figure 6— A plantation of ponderosa pine poles on a productive site grew more rapidly in basal area after thinning to higher levels of growing stock than it did to lower levels.

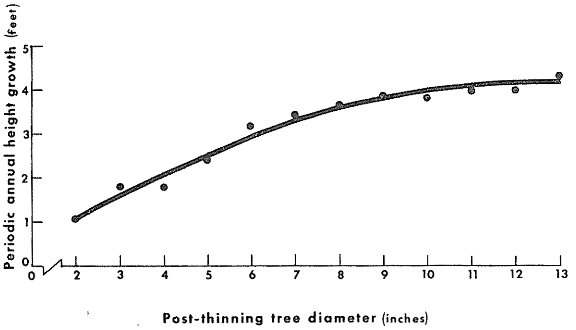

Figure 7— Height growth was related to tree size rather than growing stock level for the first 5 years after thinning a plantation of ponderosa pine on a productive site.

Basal Area

Periodic annual basal area growth was significantly and positively correlated with stand density for the 5 years since thinning *(table 3, fig. 6)*. Trees growing at GSL 40 grew 4.7 square feet per acre (1.1 m^2/ha) annually. Basal area growth increased with increasing stand density to 9.0 square feet per acre (2.1 m^2/ha) annually for GSL 160. Differences in basal area growth among stand densities were significant except between GSL 70 and GSL 100.

Height

Height growth was related strongly to tree diameter, rather than growing stock level, during the 5 years following thinning. In young, even-aged stands, larger trees usually grow faster in height than smaller trees. At Elliot Ranch, 98 percent of the variation among trees in 5-year height growth was related to post-thinning tree diameter *(fig. 7)*. No differences in this relationship among growing stock levels could be detected. The average tree in plots at higher growing stock levels did tend to grow less in height than the average tree at lower growing stock levels *(table 3)*. But this nonsignificant trend was caused by greater numbers of slower growing small trees present at the higher growing stock levels.

Crowns

Tree crowns were wide and long when the Elliot Ranch Plantation was thinned. Overall, the average tree after thinning had a crown 26 feet (7.9 m) long representing a live crown ratio of 70 percent, and 11 feet (3.4 m) wide *(table 2)*.

Since thinning, crowns widened at all stand densities, but more so at the lower growing stock levels. The crown expanded 1 foot (0.3 m) annually for trees in GSL 40 plots, decreasing linearly to 0.4 foot (0.1 m) for trees in GSL 160 plots. Differences among GSL's 40, 100, and 160 were significant *(table 3)*.

The live crown ratio, in contrast to crown width, decreased at all stand densities; but this decrease was more pronounced at higher stand densities. After 5 years, live crown ratios were reduced from the original 70 percent to 66 percent at GSL 40 and to 57 percent at GSL 160. However, the differences in rates of crown reduction among stand densities were not strong. Only the lowest (GSL 40) and the two highest stand densities (GSL's 130 and 160) differed significantly.

Volume

Stem volume production was impressive in the fully crowned trees which grew rapidly in both diameter and height. Growth in total stem volume per acre was related strongly to growing stock level during the 5 years after thinning *(fig. 8)*. Periodic annual volume growth rose at the rate of 1.3 cubic feet (0.04 m) for every square foot increase in stand basal area throughout the range of growing stock levels tested. At GSL 40, trees grew 116 cubic feet per acre (8.1 m^3/ha) annually, rising to 255 cubic feet (17.8 m^3/ha) at GSL 160 *(table 3)*. Differences in volume growth were large and significant among the lowest and highest stand densities (GSL 40 and GSL 160) and their adjacent treatment levels; whereas differences were smaller and nonsignificant among the intermediate stand densities (GSL's 70, 100, and 130) and their adjacent treatment levels.

Table 3—*Mean periodic annual growth for 5 years after thinning a plantation of ponderosa pine poles on a productive site to five growing stock levels*

Growing stock level[1]	D.b.h.	Height	Crown: Width	Crown: Ratio	Basal area	Net volume: Total[2]	Net volume: Interest rate[3]	Net volume: Merch.[4]	Largest 50 trees/acre: D.b.h.	Largest 50 trees/acre: Total volume
	Inch	*Feet*	*Feet*	*Percent*	*Sq. ft./ac*	*Cu. ft./ac*	*Percent*	*Bd. ft./ac*	*Inch*	*Cu. ft.*
40	[5]0.51	2.5	1.0	−0.7	4.7	116	14	416	0.54	73
70	0.38	2.0	0.9	−1.3	6.3	162	12	535	0.46	74
100	0.29	1.7	0.7	−1.7	6.7	167	10	431	0.41	73
130	0.25	1.7	0.6	−2.2	8.0	201	9	639	0.40	73
160	0.21	1.7	0.5	−2.4	9.0	255	10	495	0.34	72

[1]Stand density expressed as the basal area per acre that will remain after thinning when average stand diameter is 10 inches or more.
[2]Gross volume inside bark from ground line to tip less mortality.
[3]Compounded annually on net volume.
[4]Scribner board feet to a 6-inch top inside bark and an 8-foot minimum log length, i.e., most trees 9 inches d.b.h.o.b. and larger.
[5]Means significantly different at 5 percent level are unbracketed.

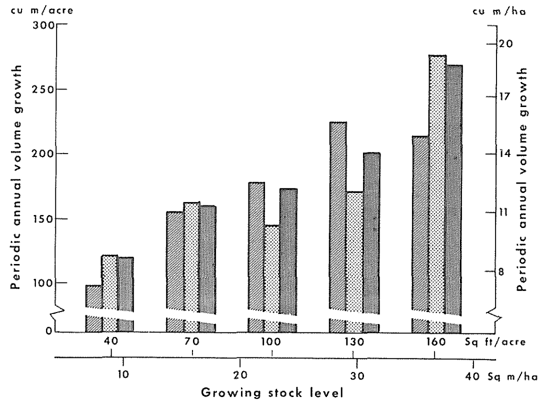

Figure 8—Volume growth was greater at higher growing stock levels for 5 years after thinning a plantation of ponderosa pine poles on a productive site.

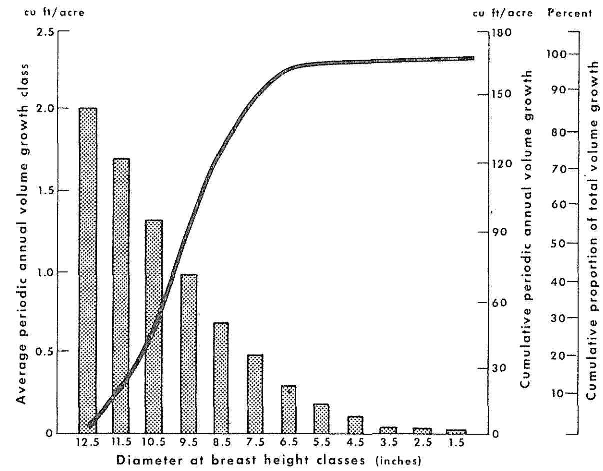

Figure 9—Annual volume growth and the cumulative volumes and proportions contributed by trees in various d.b.h. classes for 5 years after thinning a plantation of ponderosa pine poles on a productive site to growing stock level 100.

Volume growth percent also has been impressive, especially at the lower stand densities. Plots thinned to GSL 40 grew 116 cubic feet per acre (8.1 m^3/ha) annually on growing stock of only 613 cubic feet (42.9 m^3/ha) for a compound interest rate of 14 percent. Growth percent decreased slightly and leveled off at 10 percent for plots at GSL's 100 through 160.

Trees growing in stands of lower densities are individually more efficient volume producers because they are mostly large, rapidly growing, and dominant. For instance, in GSL 100 plots, trees 11.5 inches (29 cm) d.b.h. grew 1.8 cubic feet (0.05 m^3) annually; while trees 5.5 inches (14 cm) d.b.h. grew only 0.2 cubic feet (0.006 m^3) annually *(fig. 9)*. As a result, 77 percent of the volume production in plots thinned to GSL 100 was contributed by trees 8.5 inches d.b.h. (22 cm) and larger—trees larger than the average found on these plots.

The steady rise in stem volume production with increasing growing stock levels up to GSL 160 (144 ft^2/ac of basal area or 33.1 m^2/ha) sharply contrasts to the leveling off in volume production at GSL's between 80 (Schubert 1971, Oliver 1972) and 110 (Oliver 1979) found for pole-sized stands on less productive sites. Since site index at Elliot Ranch is about twice that of these less productive sites (50 to 60 against 115), I expect a concomitant rise in stand density at which maximum volume is produced. At Elliot Ranch, maximum production was not reached at GSL's below 160.

Merchantable volume growth has little meaning for tree sizes similar to those at Elliot Ranch. Small differences in diameter distributions among plots create large differences in board-foot production, obscuring the effect of growing stock level. Rapid accumulation of board feet was fueled largely by ingrowth into merchantable sizes. The smallest tree considered merchantable was 9 inches (23 cm) d.b.h. capable of producing an 8-foot (2.4-m) log with a 6-inch (15-cm) diameter inside bark at the small end—intensive utilization by today's standard. The proportion of trees reaching this merchantable size averaged 31 percent for all plots during the 5 years since thinning. The proportion tended to be greater at lower growing stock levels.

DAMAGE AND MORTALITY

Tree injury and death have had little influence on 5-year results *(table 2)*. A heavy, wet snowfall in winter 1970 caused nearly all damage and mortality. Stems broke at or below the crown base, killing 39 trees or 1.9 percent of all trees in the study. Also included as dead were a few living trees cut during a clean-up in the spring following the storm. Since most of the crown had broken out of these trees, I expected them to die soon. If not removed, they might have bred bark beetles.

Snow broke the upper crowns or bent the stems of 9.4 percent of all study trees. Damage from an earlier storm at the Elliot Ranch Plantation was greater in stands of higher densities than in stands of lower densities (Powers and Oliver 1970). I found a similar but nonsignificant trend in both damage and mortality after the 1970 storm.

CONCLUSIONS

A periodic annual volume growth of 255 cubic feet per acre (17.8 m^3/ha) reported in this study for plots growing at GSL 160 may seem unusually high. However, this growth rate is about that predicted by Meyer (1938) and Oliver and Powers (1978). It compared favorably with rates reported for similar plantations of loblolly and slash pine in the southern United States (Feduccia and Mann 1976, Mann and Enghardt 1972).

Plantations often grow faster than comparable natural stands, especially at young ages, because competition among trees and with other vegetation is reduced. At Elliot Ranch, deerbrush was plentiful but scarcely retarded growth and development of the plantation because moisture and nutrients were abundant. Stocking control, through planting which resulted in less intertree competition, influenced thinning response profoundly. Before thinning, the uniformly spaced leave trees were healthy and vigorous, as indicated by an average live crown ratio of 70 percent. Periodic annual growth in both diameter and volume was at its peak (Meyer 1938, Oliver and Powers 1978). After thinning, when the stand was 20 years old, leave trees responded immediately to the added space made available. But only trees in plots thinned to the two lightest growing stock levels—GSL 40 and GSL 70—grew faster in diameter after thinning than before. And the increased growth of trees in GSL 70 plots was fleeting, lasting only 2 years. Diameter growth of trees at all higher growing stock levels continued their normal decline following culmination of periodic annual growth. Live crown ratio was not stimulated by thinning even to GSL 40, because leave tree crowns were full before thinning. Instead, thinning slowed the decline in live crown ratio which is normal with advancing age regardless of stand density.

Board-foot volume growth remained nearly constant and total volume growth increased linearly with increasing growing stock levels throughout the range of levels tested. Although not tested, unthinned plots probably would have grown in total stem volume at a rate even faster than GSL 160 plots. If so, thinning in plantations not under severe intertree competition may be at the sacrifice of potential volume production. But the growth loss has no practical importance because thinnings from pole-sized plantations have little commercial value in today's market.

Since thinning may reduce per acre growth (even though the volume lost is presently without commercial value), what advantages are gained by thinning these "high site" ponderosa pine plantations? Shortening the time to reach merchantable size is a major advantage. Growth of GSL 160 plots may seem adequate, but thinning to GSL 100 will bring the plantation to merchantable size 15 years sooner—at age 35 years for GSL 100 against age 50 for GSL 160, assuming that the plantation would be thinned once when pole-sized and that a mean stand diameter of 12 inches soon will be minimum merchantable size (yielding trees 9 to 12 inches in a low thinning).

Another advantage of thinning is stand health. Densities in unthinned plantations approaching 300 square feet of basal area per acre at age 50 are likely. Growth losses, including mortality, from intertree competition and possibly bark beetles (Sartwell and Stevens 1975) could be substantial. By contrast, stands thinned to GSL 100 could reach 200 square feet of basal area per acre at age 35 years. This density is sufficient to support a commercial thinning, but probably not dense enough to jeopardize stand health on this productive site.

Precommercial thinning pole-sized plantations is not recommended. Thinning is costly. Also, the huge volume of slash creates an unacceptable fire and insect hazard. The cost to mitigate this hazard often is prohibitive. Thinning when trees have reached sapling size usually reduces thinning costs and slash volumes to acceptable levels.

These conclusions are based upon stand density-growth relationships found in only one plantation. Although they seem reasonable, the conclusions may not apply to other plantations.

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Retrieval Terms: Pinus ponderosa, stand density-growth, diameter growth, basal area growth, volume growth, stocking level, plantation, California.

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