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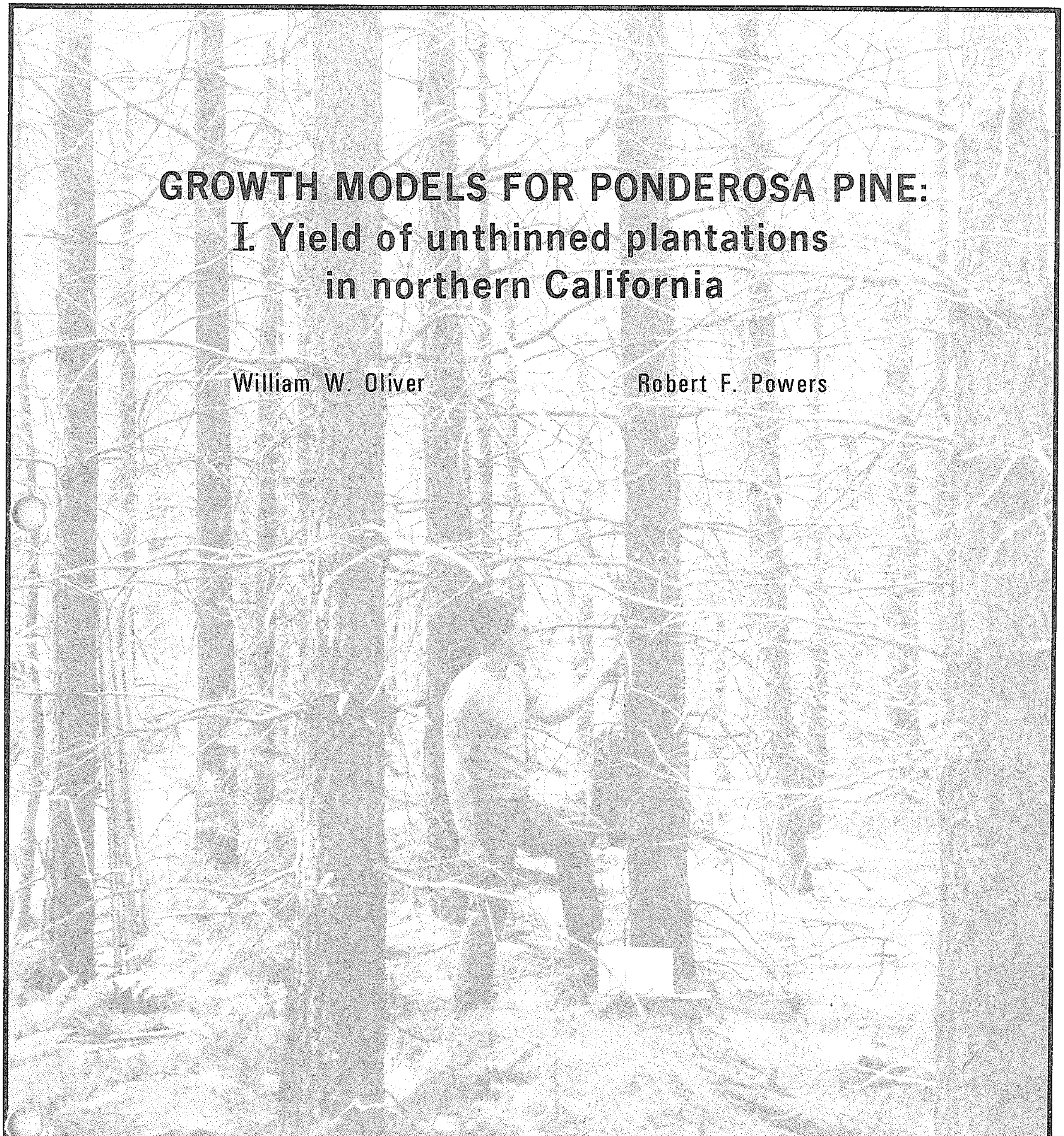

GROWTH MODELS FOR PONDEROSA PINE:
I. Yield of unthinned plantations in northern California

William W. Oliver   Robert F. Powers

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IN BRIEF...

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Oxford: 174.7 *Pinus ponderosa* — 566 [+612]
Retrieval Terms: Pinus ponderosa; plantations; growth models; yield tables; basal area; volume; northern California.

Yields of unthinned ponderosa pine (*Pinus ponderosa* Laws.) plantations with high initial survival, negligible brush competition, and low mortality from external causes were estimated by a growth model. Data were obtained from 367 trees in 12 plantations in the southern Cascade Range, northern Sierra Nevada, Klamath Mountains, and Warner Mountains of northern California. Sampled plantations represented a wide range of initial spacings — 3 by 3 feet to 12 by 12 feet (1 by 1 m to 3.7 by 3.7m) and site indices from 35 to 120 feet (10.7 to 36.6 m) at 50 years total age (Powers and Oliver 1978).

Plantation yields were determined from stem analyses of individual trees by this procedure:

1. For each of four crown classes, the linear relationship of d.b.h. to the product of spacing and height above breast height was determined.

2. Heights of dominant trees were obtained from site index curves (Powers and Oliver 1978). Heights of codominant and intermediate crown classes were obtained from equations relating their heights to those of dominant trees (Oliver and Powers 1971). The relationship of suppressed to dominant tree height was estimated.

3. To obtain stand yields, curvilinear relationships between crown class proportions and the product of trees per acre and dominant height were determined.

4. Number of trees was reduced initially by 15 percent to account for mortality from planting shock. Mortality from intertree competition was distributed by crown classes after a maximum stand density was reached.

5. The following cubic volume equation was developed because existing volume tables were inaccurate for plantations:

$$V = 0.024843 + 0.0017645\ D^2H$$

in which

V = Volume in cubic feet inside bark from 1-foot (0.3-m) stump to tip

D^2H = the product of d.b.h. squared and total height.

6. The net cubic volumes that resulted were smoothed by four spacing-dependent equations.

Tables showing diameter, basal area, and net cubic volume yields by Site Indices$_{50}$ 40 through 120 were compiled for stands ranging in age between 10 and 50 years and in spacing between 6 by 6 and 12 by 12 feet (1.8 by 1.8 and 3.7 by 3.7 m). Also reported are diameter distributions by crown classes and stem volumes in cubic feet.

Model predictions were compared with observations from real stands. The model explained the following percentages of variation — 89 percent about the mean diameter, 78 percent about the mean basal area, and 92 percent about the mean cubic volume per acre. We were disappointed that the model underestimated net cubic volume per acre. Predicted volume averaged 187 cubic feet less than observed — a significant difference. Six of the 35 plots in real stands were from the only plantation in the Warner Mountains, however. Volumes were underestimated for all six plots. When they were excluded, the difference between predicted and observed volumes was not significant, and the number of over- and underestimated volumes was more nearly equal.

Ponderosa pine (*Pinus ponderosa* Laws.) has been planted extensively for timber production in northern California. In the last 15 years the Forest Service, U.S. Department of Agriculture, alone has planted more than 130,000 acres (53,000 ha).[1] Most of these plantations are managed intensively yet growth and yield information is inadequate — especially for plantations growing on highly productive sites. Lack of reliable data on plantation development on different site qualities at different initial spacings hinders important management decisions, such as choice of initial spacings, thinning schedules, and brush control strategies.

Simulated yields for high-survival plantations developing with little brush competition or disturbance often are greater than those found in practice, especially over large areas. Inclusions of nonproductive areas, irregular spacing, and steep slopes can reduce yields (Bruce 1977). Nevertheless, these data provide both a standard with which to compare the effects of management decisions, and a performance goal.

This paper suggests the yield potential of unthinned ponderosa pine plantations with high initial survival, negligible brush competition, and low mortality from external causes. It is the first of three reports on growth models for ponderosa pine. The second report will examine the maximum growth potential of the species, and the third, stem and crown growth of individual trees in plantations.

THE PLANTATIONS

Yields were derived from 367 trees in 12 plantations in the southern Cascade Range, northern Sierra Nevada, Klamath Mountains, and Warner Mountains (Basin and Range Province) of northern California (*table 1, fig. 1*). Sample trees were measured in plantations which had (a) high initial survival, (b) closed canopies, (c) regular spacing, (d) negligible insect, disease, or storm damage, (e) no thinning, and (f) negligible brush competition. Plantations ranged in age from 16 to 50 years, in d.b.h. from 4 to 13 inches (10 to 33 cm), and in height from 17 to 69 feet (5 to 21 m). Sampled plantations represented a wide range of initial spacings — 3 by 3 feet to 12 by 12 feet (1 by 1 m to 3.7 by 3.7 m) and site indices from 35 to 120 feet (10.7 to 36.6 m) at 50 years total age (Powers and Oliver 1978).

[1]Data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

Table 1—*Characteristics of ponderosa pine plantations sampled for yield model*

Plantation	Province	Elevation		Age	Site Index$_{50}$		Spacing		Trees sampled
		(Ft)	*(M)*	*(Yrs)*	*(Ft)*	*(M)*	*(Ft)*	*(M)*	
1-Shasta Lake	Klamath Mtns.	1700	518	34	40-55	15	8	2.4	30
2-Henry's Find	Cascade Range	3800	1159	46	75	21	8	2.4	20
3-Show	Cascade Range	3900	1190	50	75	23	12	3.7	38
4-Shingletown	Cascade Range	3600	1098	25	70	21	7	2.1	30
5-Sugar Hill	Basin and Range	5400	1647	38	35-55	11-17	8-9	2.4-2.7	60
6-Quincy	Sierra Nevada	3400	1037	28	35	11	3	0.9	30
7-Bloody Run	Sierra Nevada	4400	1342	21	100	30	7	2.1	30
8-Elliot Ranch	Sierra Nevada	4000	1220	20	105	32	7	2.1	30
9-Hazel Valley	Sierra Nevada	2800	854	16	105	32	6	1.8	10
10-Fraser Flat	Sierra Nevada	4900	1494	29	70-80	21-24	7	2.1	29
11-Wright's Creek	Sierra Nevada	4800	1464	18	100	30	7	2.1	30
12-The Basin	Sierra Nevada	3500	1068	16	90-120	27-37	4-5	1.2-1.5	30

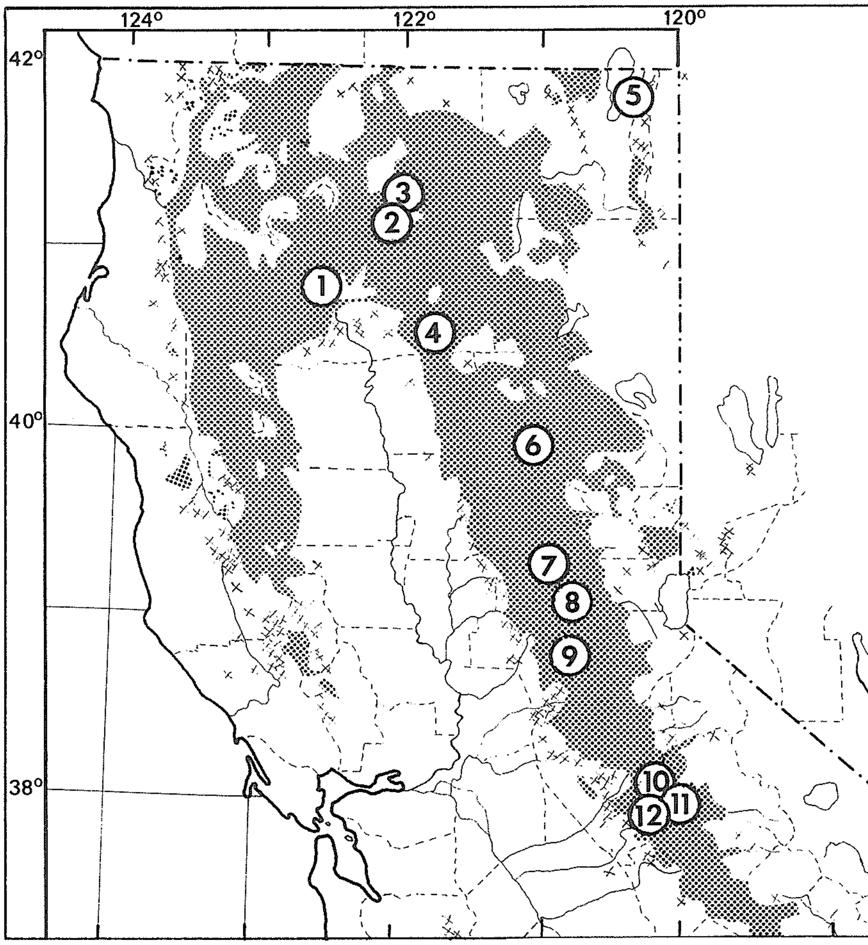


Figure 1—Location of ponderosa pine plantations sampled for growth model. Base map showing distribution of ponderosa pine in northern California. (From Griffin and Critchfield 1972)

METHODS

Field Procedures

Yield

At least 10 trees, representing about equal numbers of dominant, codominant, and intermediate crown classes, were selected for detailed measurements within a 0.05- to 0.1-acre (0.02- to 0.04-ha) area. Some trees within these areas were rejected because of damage or irregular spacing. From one to five of these 10-tree clusters were measured in each selected plantation. Data recorded for each tree were:

a. Age from planting

b. Crown class

c. D.b.h. to nearest 0.1 inch (0.25 cm)

d. Distance to nearest 0.1 foot (0.03 m) to adjacent trees both within and between rows

e. Past diameter and height for the first 10 years after reaching breast height, at 5-year intervals thereafter, and at present.

Ages from time of planting were determined from records. Ages of two plantations that had no records were estimated by adjusting breast height age from increment cores by years to reach breast height (Oliver and Powers 1971).

Past diameters were determined from annual ring patterns of three increment cores extracted in a flat spiral pattern at 120° intervals around the stem at breast height (Powers 1969). Past heights were measured at branch whorls with a graduated pole for trees up to 40 feet (12 m) in height. Taller trees were measured with a clinometer.

Volume

We developed a cubic volume equation specifically for plantation-grown ponderosa pine because existing volume tables were inaccurate for plantations. Data came from 425 trees which included 117 trees in nine of the 12 plantations sampled in this yield study plus five plantations with similar characteristics, and an additional 308 trees from four existing thinning studies.[2] Sample trees ranged in d.b.h. from 1 to 24 inches (2.5 to 61.0 cm) and in height from 5 to 95 feet (2 to 29 m).

Stem volumes were determined from sets of outside bark diameters and lengths between diameter measurements from a 1-foot (0.3-m) stump to tree top. Diameters were recorded to the nearest 0.1 inch (0.25 cm) and lengths to the nearest 0.1 foot (0.03 m). The number of measurement sets depended upon the size of the tree and locations of rapid form changes. Saplings required, at a minimum, measurement sets at stump, breast height, and total height. Small sawtimber required additional measurements at bases of live crowns and midcrowns. Double bark thickness was estimated to be 0.1765 times the stem diameter (Powers 1969). Trees less than 20 feet (6 m) tall were measured directly with a diameter tape and graduated pole. An optical dendrometer or optical caliper and clinometer were used for measuring taller trees.

Office Procedures

Volume

Stem volumes inside bark in cubic feet were calculated either by Grosenbaugh's (1974) STX computer program or by a similar method using a desk-top computer.

When volumes were plotted over the product of d.b.h. squared and total height (D^2H) (Spurr 1952), differences among volumes of trees planted at different spacings on sites of different productivities could not be found except in one plantation. Trees in this dense, experimental plantation with over 2800 stems per acre (6900 per ha) contained higher volumes for a given D^2H than did trees in more widely spaced plantations. Because this density is higher than that found in practice, these data were not included. One equation was considered adequate for all common site qualities and spacings.

Two weighted, least-squares solutions of the combined-variable formula $V = a + bD^2H$ were computed and compared with the unweighted solution. Weights tested were $1/D^2H$ and $1/(D^2H)^2$. The weight $1/D^2H$ gave a more precise estimate than either weighting with $1\ (D^2H)^2$ or the unweighted solution. Residual error, according to Furnival's (1961) Index of Fit, was reduced substantially. The ratio of the standard error of the unweighted expression to the transformed standard error of the expression weighted by $1/D^2H$ was 2.14. This combined-variable equation of best fit is:

$$V = 0.024843 + 0.0017645\ D^2H$$

Transformed standard error = 0.746

in which

V = Volume in cubic feet inside bark from 1-foot (0.3-m) stump to tip

Table 2 was constructed using this formula.

Yield

Plantation yields were determined from stem analyses of individual trees by this procedure:

Diameter — Trees were grouped into crown classes. Within each crown class all past and current diameters and heights of each tree and its average linear spacing were fitted by least squares to the expression:

$$\ln Y = a + b \ln X$$

in which

$\ln Y$ = natural logarithm of d.b.h.

$\ln X$ = natural logarithm of the product of linear spacing and height above breast height.

Because we observed many more of the smaller values of the independent variable, the regression coefficients were calculated from the average diameter for each 50 units of the independent variable.

Too few suppressed trees were available to fit the relationship by least squares. Nevertheless, an equation with an intercept constant similar to that of the equation for the intermediate crown class and a slope coefficient 82 percent of that for the dominant crown class seemed to fit the available data well. These equations were obtained and data plotted *(fig. 2)*:

Dominant

$\ln Y = -1.6107 + 0.6625 \ln X$

$Sy.x = 0.116$

$r = 0.98$

[2]Data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

Table 2—*Volumes for plantation- grown ponderosa pine in cubic feet inside bark from 1-foot stump to tip*

D.b.h., o.b. (inches)	Total height (feet): 5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110
1	0.03	0.04	0.05																			
2	0.06	0.10	0.13	0.17	0.20																	
3	0.10	0.18	0.26	0.34	0.42	0.50	0.58															
4		0.31	0.45	0.59	0.73	0.87	1.01	1.15														
5		0.47	0.69	0.91	1.13	1.35	1.57	1.79	2.01	2.23												
6		0.66	0.98	1.30	1.61	1.93	2.25	2.57	2.88	3.20	3.52	3.84										
7			1.32	1.75	2.19	2.62	3.05	3.48	3.92	4.35	4.78	5.21	5.64	6.08	6.51							
8				2.28	2.85	3.41	3.98	4.54	5.11	5.67	6.24	6.80	7.36	7.93	8.49	9.06						
9				2.88	3.60	4.31	5.03	5.74	6.46	7.17	7.89	8.60	9.31	10.03	10.74	11.46	12.17					
10				3.55	4.44	5.32	6.20	7.08	7.97	8.85	9.73	10.61	11.49	12.38	13.26	14.14	15.02	15.91				
11				4.29	5.36	6.43	7.50	8.56	9.63	10.70	11.77	12.84	13.90	14.97	16.04	17.11	18.17	19.24	20.31			
12					6.38	7.65	8.92	10.19	11.46	12.73	14.00	15.27	16.54	17.81	19.08	20.35	21.62	22.89	24.16	25.43		
13					7.48	8.97	10.46	11.95	13.44	14.93	16.43	17.92	19.41	20.90	22.39	23.88	25.37	26.86	28.35	29.84	31.34	
14					8.67	10.40	12.13	13.86	15.59	17.32	19.05	20.78	22.50	24.23	25.96	27.69	29.42	31.15	32.88	34.61	36.34	38.07
15						11.94	13.92	15.91	17.89	19.88	21.86	23.85	25.83	27.82	29.80	31.79	33.77	35.76	37.74	39.73	41.71	43.70
16							15.83	18.09	20.35	22.61	24.87	27.13	29.39	31.64	33.90	36.16	38.42	40.68	42.94	45.20	47.45	49.71
17							17.87	20.42	22.97	25.52	28.07	30.62	33.17	35.72	38.27	40.82	43.37	45.92	48.47	51.02	53.57	56.12
18							20.03	22.89	25.75	28.61	31.47	34.33	37.18	40.04	42.90	45.76	48.62	51.48	54.34	57.19	60.05	62.91
19								25.50	28.69	31.87	35.06	38.24	41.43	44.61	47.80	50.98	54.17	57.35	60.54	63.72	66.91	70.09
20								28.56	31.79	35.31	38.84	42.37	45.90	49.43	52.96	56.49	60.02	63.55	67.08	70.60	74.13	77.66
21									35.04	38.93	42.82	46.71	50.60	54.49	58.39	62.28	66.17	70.06	73.95	77.84	81.73	85.62
22									38.46	42.73	47.00	51.27	55.54	59.81	64.08	68.35	72.62	76.89	81.16	85.43	89.70	93.97
23										46.70	51.36	56.03	60.70	65.36	70.03	74.70	79.37	84.03	88.70	93.37	98.03	102.70
24										50.84	55.92	61.01	66.09	71.17	76.25	81.33	86.41	91.50	96.58	101.66	106.74	111.82
25											60.68	66.19	71.71	77.22	82.74	88.25	93.76	99.28	104.79	110.31	115.82	121.33

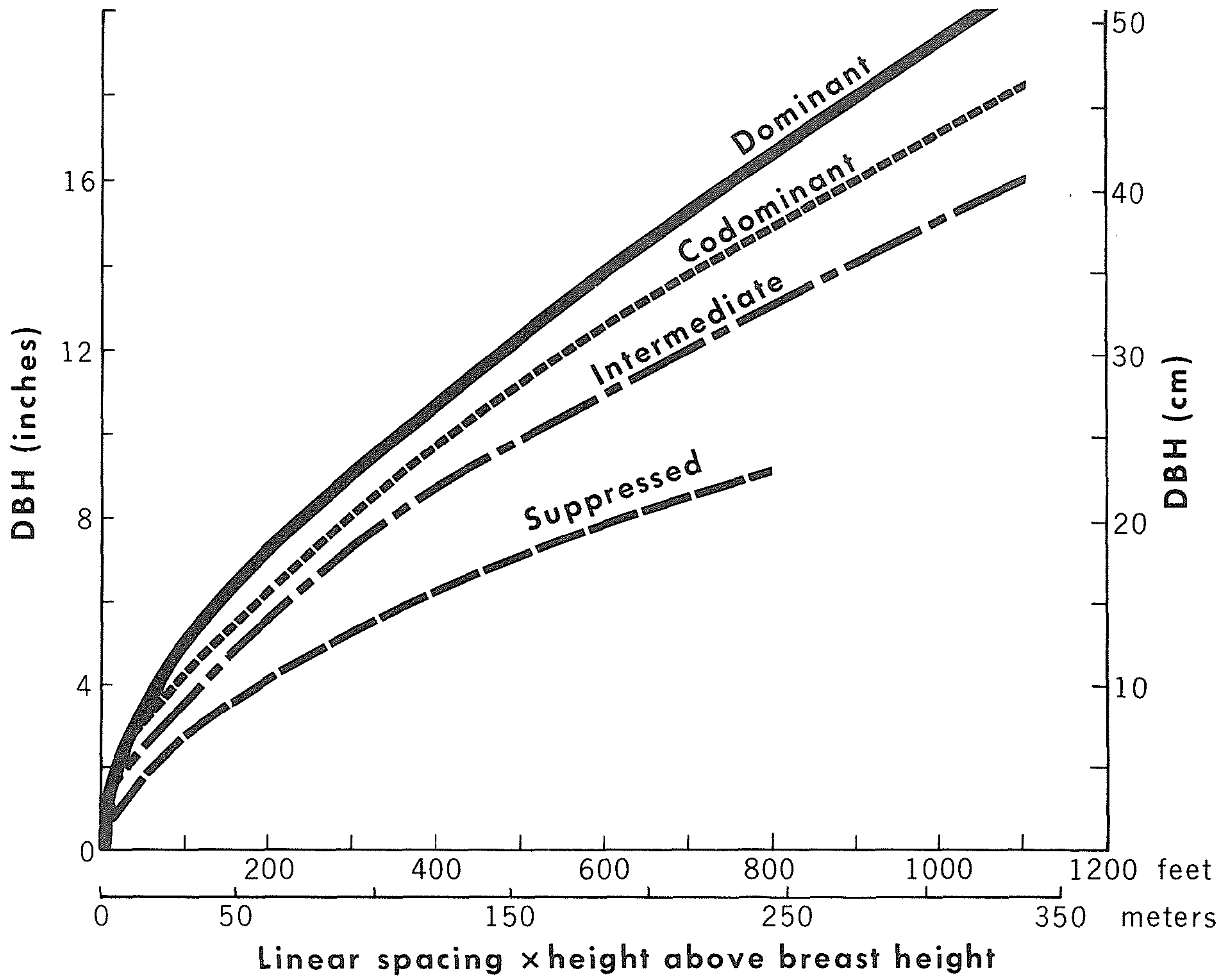


Figure 2—Breast height diameter was related to spacing and height for planted ponderosa pine of four crown classes.

Codominant

$\ln Y = -1.4217 + 0.6173 \ln X$

$Sy.x = 0.114$

$r = 0.98$

Intermediate

$\ln Y = -1.4332 + 0.6008 \ln X$

$Sy.x = 0.056$

$r = 0.97$

Suppressed

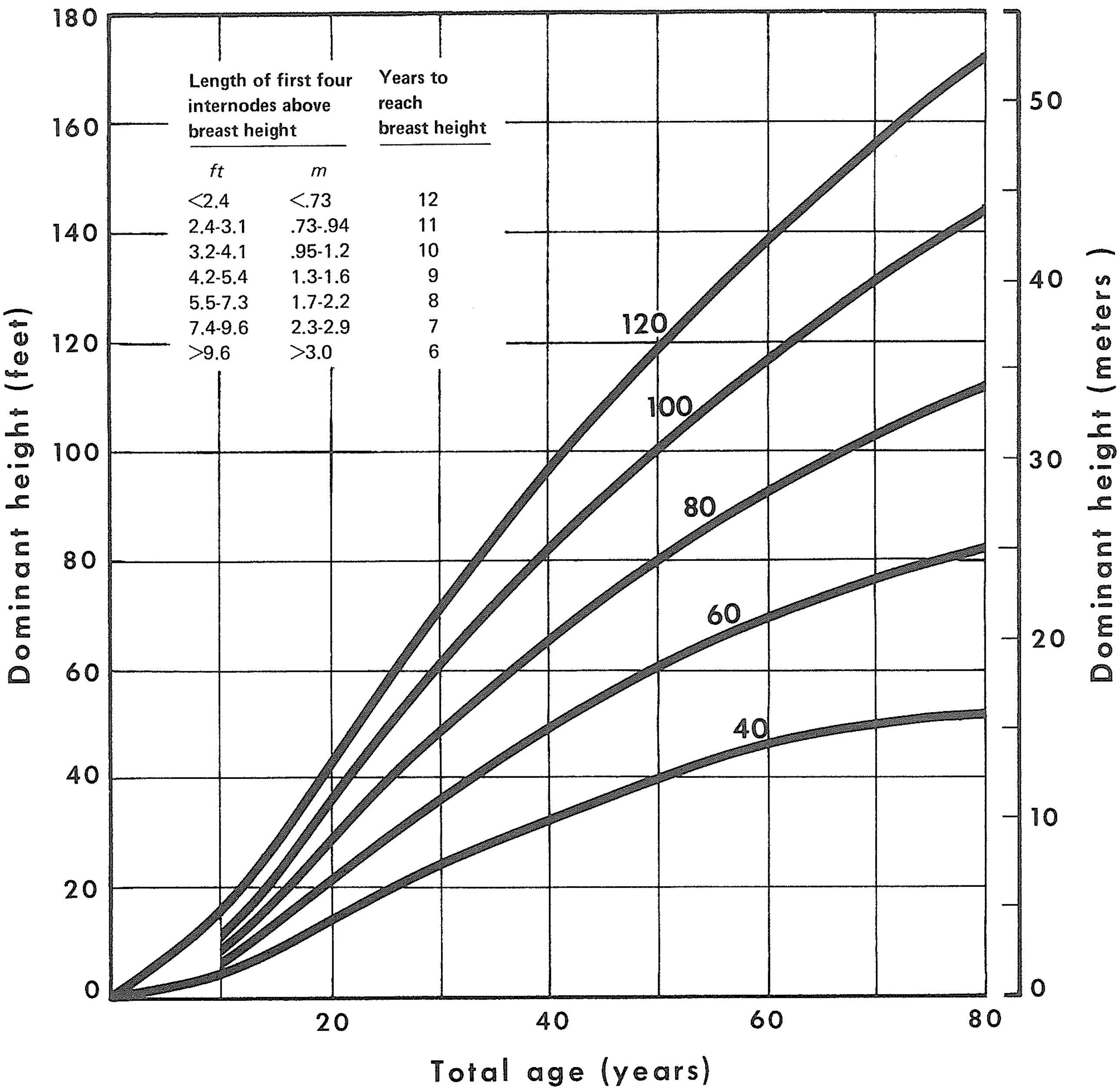
$\ln Y = -1.4 + 0.54 \ln X$

Height — Mean dominant heights for given ages and site indices were taken from recently developed site index curves (Powers and Oliver 1978). These curves for plantations and young natural stands of ponderosa pine in California were derived in part from trees used in this study *(fig. 3)*.

Mean heights of codominant and intermediate crown classes were obtained from equations relating their heights to those of dominant trees (Oliver and Powers 1971). Again, because data on suppressed trees were meager, their average heights were estimated to be 40 percent of mean dominant height.

We assumed that height growth is not significantly affected by spacing. Therefore, in constructing this growth model, tree heights for a given crown class, age, and site index are the same regardless of spacing. At extremely high stand densities this is untrue (Oliver 1967). But within the range of densities normally encountered in plantations, it seems to be a reasonable assumption.

The equations relating d.b.h. to spacing and height were combined with site index and heights of subordinate crown classes to construct tables of heights and diameters by age, site index, and crown class *(Appendix, tables 10-14,* in part).



Site index curves for plantations and young natural stands of ponderosa pine

Figure 3—Site index curves for even-aged westside ponderosa pine developed from stem analyses. Adjustment factors are shown for converting breast height age to total age. (From Powers and Oliver 1978)

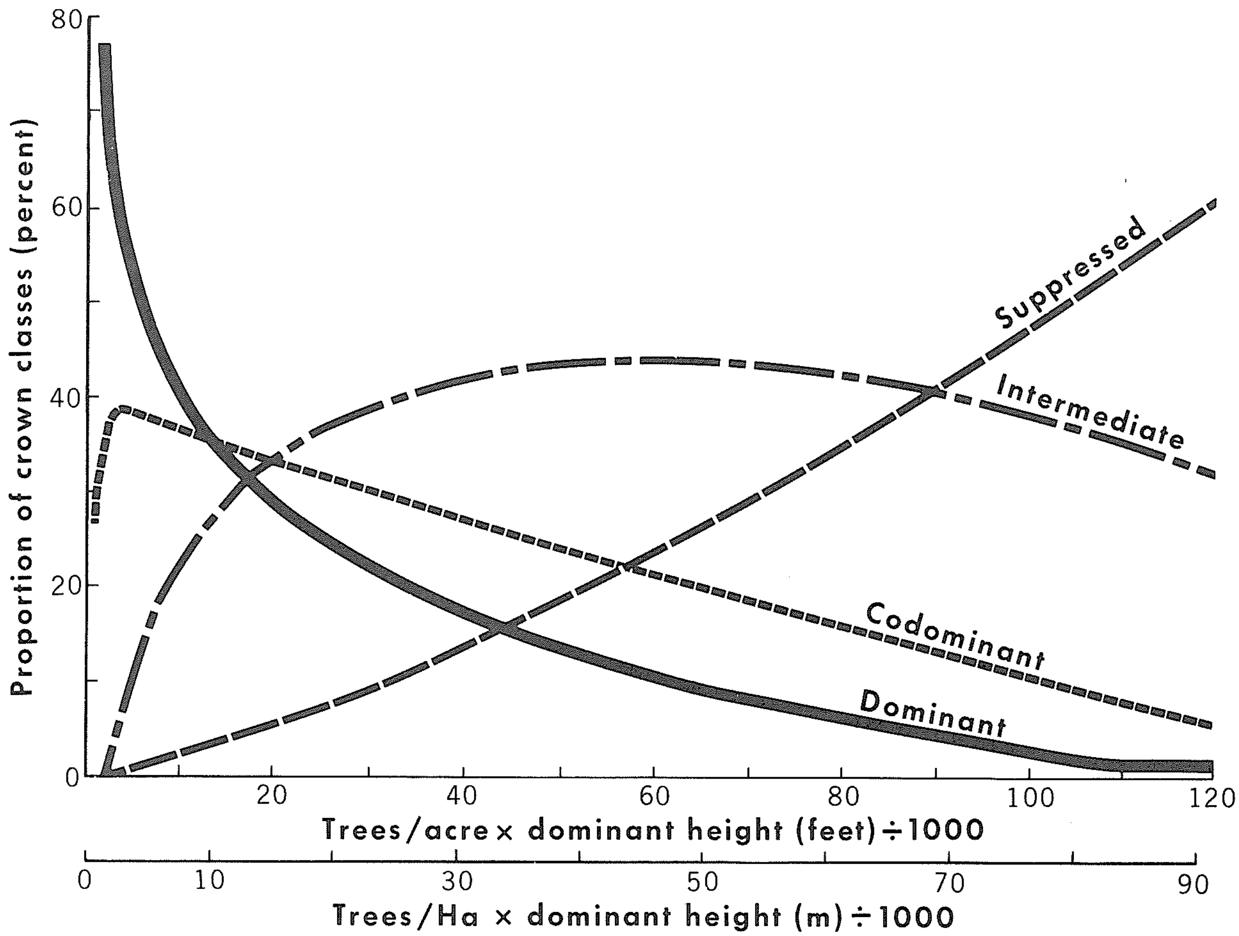


Figure 4—Crown class proportions in unthinned ponderosa pine plantations were related to number of trees per acre and dominant height.

Crown Class — We had the basis for estimating yields from the four crown class components. But, to combine these components into stand yield estimates required information on crown class proportions and mortality, and especially on changes occurring with spacing and time.

We counted the number of trees in each crown class and expressed it as a proportion of total trees in the plantations sampled for stem volume. These data, combined with existing information,[3] were plotted over several expressions of spacing times dominant height. The best expression found was trees per acre multiplied by dominant tree height. Correlation coefficients were highly significant for dominant and suppressed crown classes (r = 0.71 and 0.74, respectively), but not significant for codominant crown classes (r = 0.29). No pattern was discernible for intermediate crown classes.

The relationships fitted by least squares were plotted for dominant, codominant, and suppressed classes. Hand adjustment of the curve for dominants was necessary to make it asymtotic at higher values of the independent variable and for codominants to reflect the rapid buildup of this crown class at lower values of the independent variable. The curve for intermediates was constructed from the remainder after subtracting the other three proportions from 100 percent. The resulting curve was biologically valid and fit the plotted data well. Values were read from these plotted relationships *(fig. 4)* to calculate number of trees per acre for each crown class by spacing and height.

Mortality — We found little evidence of mortality after the initial decline commonly attributed to planting shock. Consequently, we reduced the number of trees

[3]Data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

per acre initially by 15 percent[4] to account for early mortality and planting skips.

No further reductions in number of trees per acre were calculated until average stand diameter for a given nominal spacing produced a maximum stand density. This maximum density, roughly equivalent to a Stand Density Index of 500 (Reineke 1933), was determined from a survey of dense, natural, even-aged stands in northern California.[5] It can be expressed by this equation fitted by least squares:

$$\ln N = 10.2687 - 1.7712 \ln D$$

in which

$\ln N$ = natural logarithm of number of trees per acre.

$\ln D$ = natural logarithm of mean stand d.b.h. in inches.

Total number of trees per acre was then reduced for each 5-year period using this relationship.

Crown classes, however, differ in their susceptibility to death from intertree competition. More trees in subordinate crown classes die than do trees in dominant crown classes. Larson (1975), using meager published information, derived this relationship:

$$Y = 0.276 + 0.003\,(X-22)^2$$

in which

Y = average annual mortality in percent by d.b.h. for natural stands 10 years after partial cutting

X = d.b.h. in inches.

Lacking data more appropriate, we applied Larson's mortality data. The resulting percentages were proportioned to total 100 percent and balanced by the numbers of trees in each crown class. Different rates of mortality could then be distributed to each crown class.

Volume Equations — A multivariate equation helped smooth the net cubic volume yields obtained through the model. The following equation form was chosen to reproduce model volumes as closely as possible. We did not attempt to represent the effect of age and site on volume as it occurs in nature and no biological significance should be attributed to the variables or their transformations.

$$\ln Y = \alpha_0 + \alpha_1 A + \alpha_2 S + \alpha_3 A^2 + \alpha_4 S^2 + \alpha_5 A^4 S^2 + \alpha_6 A^2 S + \alpha_7 A\,S^2$$

in which

$\ln Y$ = natural logarithm of net volume yield in cubic feet,

A = 1/age since planting

S = site index,

α_{0-7} = coefficients which vary by spacing (*table 3*).

[4]Average mortality of successful ponderosa pine plantations in northern California based on our conversations with practicing foresters.

[5]Data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

Table 3—*Coefficients for the equation relating net cubic volume yield to plantation age and site index depend upon spacing*

Spacing (*Ft*)	Coefficients							
	α_0	α_1	α_2	α_3	α_4	α_5	α_6	α_7
	X10⁰ → $X10^{0}$	$X10^{0}$	$X10^{-2}$	$X10^{0}$	$X10^{-4}$	$X10^{-1}$	$X10^{0}$	$X10^{-3}$
6	7.087370	-114.20401	7.9771886	768.61946	-5.0313026	9.112518	-9.264435	6.634481
8	6.991414	-115.78540	8.1689434	695.84398	-4.7486534	9.841982	-8.059382	5.696333
10	6.850749	-113.62627	8.2534706	599.46115	-4.511247	10.361767	-6.835023	4.846406
12	6.768138	-111.30262	8.1463585	507.31706	-4.1865322	9.570306	-5.409514	3.970905

TESTING THE MODEL'S PREDICTIVE ABILITY

To test our model's predictive ability, we needed real data from new stands. Because of the scarcity of older, well-stocked plantations in California, some of our check data came from 10 of the 12 plantations used in constructing the model. We either measured fixed-area plots in new areas, or in our old areas several years after our first visit. Eight additional plantations were sampled and the files searched for existing data. We found 35 plots suitable for testing the model's predictive ability, though all were not strictly independent of the model.

An evaluation of predicted stand characteristics with observations in ponderosa pine plantations is shown (*table 4*). The model explained these percentages of variation: 89 percent about the mean diameter, 78 percent about the mean basal area per acre, and 92 percent about the mean cubic volume per acre. Nearly half of the predictions of mean stand diameter were within ± 10 percent of the observations, and only 3 of the 35 were beyond ± 25 percent. Slightly more than half of the time the model overestimated mean stand diameter. But this overestimate averaged less than 0.1 inch (0.25 cm).

Variation between observed and predicted basal area and volume was greater than that for diameter. About one-third of the predicted values were within ± 10 percent of the observed and two-thirds were within ± 25 percent. In contrast to stand diameter, predicted values of basal area and volume were less than observed about two-thirds of the time. Predicted basal area averaged 10 square feet less than observed — a nonsignificant difference. Predicted volume averaged 187 cubic feet less than observed. This difference was statistically significant.

We were disappointed that the model failed to predict stand volumes better. The significant difference between predicted and observed stand volumes, however, may be attributed to the large number of observations in one disjunct plantation. Six of the 35 test plots were from the extensive Sugar Hill Plantation — the only plantation sampled in the Basin and Range Province in northeastern California. Volumes were underestimated for all six plots. When the Sugar Hill plots were excluded, the difference between predicted and observed volumes was not significant, and the number of over- and underestimated volumes was more nearly equal. These yield predictions may be invalid for northeastern California. More likely, however, the Sugar Hill Plantation is uniquely productive, because yields from similar plantations in central Oregon, outside the range of the original data, were not underestimated. Unfortunately, this question must remain unresolved because unthinned plantations of similar age do not exist in northeastern California.

Table 4—*Evaluation of observed stand characteristics with those predicted in ponderosa pine plantations in northern California*

Stand characteristics	R^2	Observed values in relation to predicted		Observed values less predicted values		t-value for test of 0 difference[1]
		±10 Pct.	±25 Pct.	Negative	Positive	
		Percent of plots tested				
Diameter	0.89	46	91	54	43	0.373
Basal area	0.78	34	63	40	57	1.608
Net cubic volume (Sugar Hill Plots included)	0.92	34	71	32	68	2.514
Net cubic volume (Sugar Hill Plots excluded)	0.94	45	79	39	61	1.151

[1] Value of "t" with probability 0.05 and 30 degrees of freedom is 2.042.

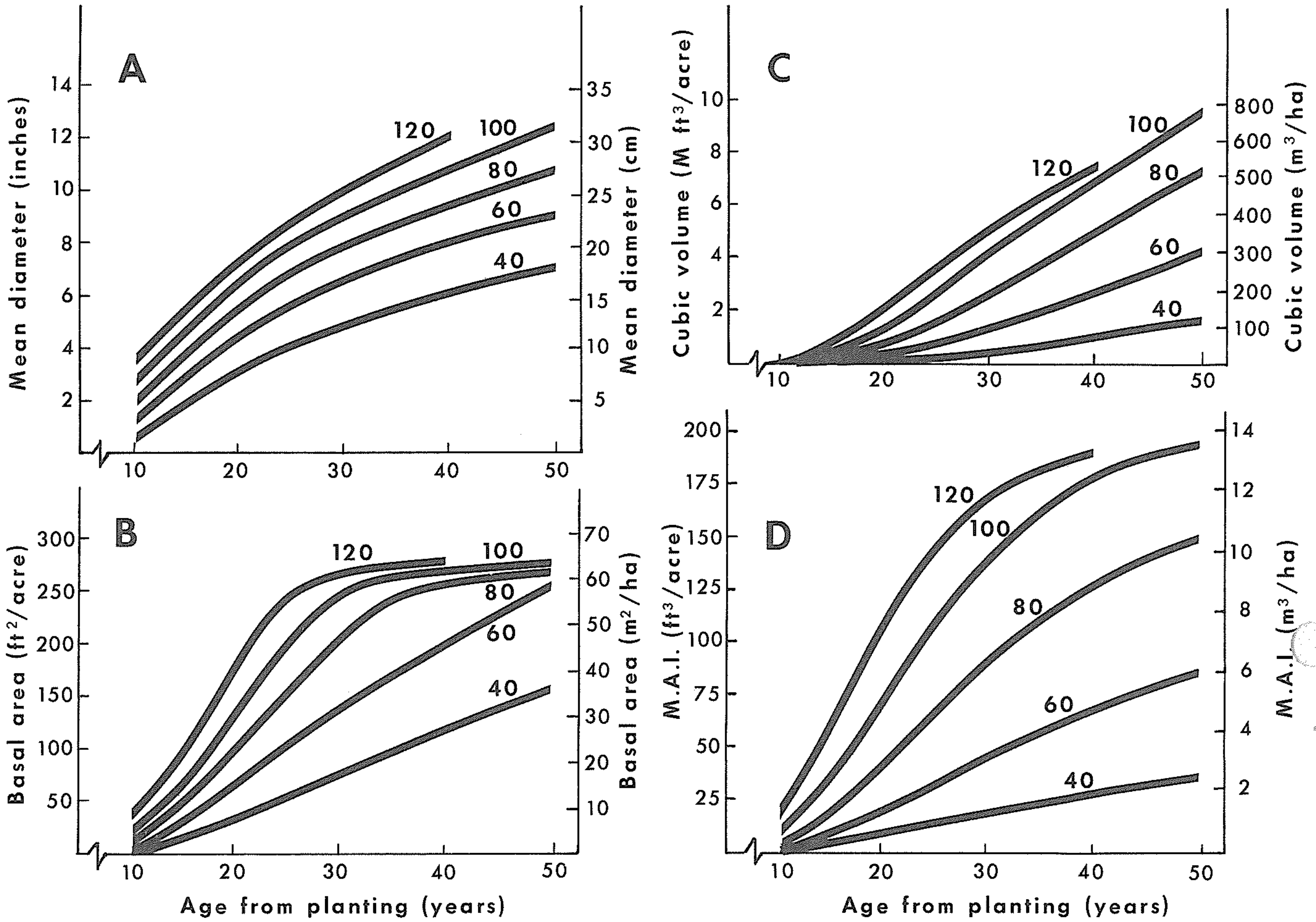


Figure 5—Predicted stand characteristics for ponderosa pine planted at 8 X 8 Site Indices 40 to 120 and ages 10 to 50 years. *A.* mean stand diameter, *B.* net basal area, *C.* net cubic volume, *D.* mean annual volume increment.

THE YIELD TABLES

The yield tables in this report (*Appendix, tables 5-14*) represent the natural development of high-survival, unthinned ponderosa pine plantations in northern California. Yields are presented first by site indices in increments of 20 feet (6.1 m) from Site $Index_{50}$ 40 through 120. Within each site index, yields are given every 5 years from 10 to 50 years and for 6-, 8-, 10-, and 12-foot (1.8-, 2.4-, 3.0-, and 3.7-m) spacings (*Appendix, tables 5-9*).

Stand averages are insufficient for making certain management decisions, such as time of earliest commercial thinning. In addition, diameter distributions by crown classes are needed (*Appendix, tables 10-14*).

Some of the relationships (*fig. 5*) are discussed below. For conciseness, only relationships for the 8-foot (2.4-m) spacing are displayed. When spacing effects are discussed, their trends can be verified from the tables.

Mean Stand Diameter

As plantation spacing and site index increase, mean stand diameter increases. In general, diameter increases with age, also. But for 6-foot (1.8-m) spacings at Site Index 120 (37 m) growth is negligible above age 35 (*Appendix, table 9*), indicating growth stagnation caused by high stand density. Periodic annual increment in diameter culminates at 10 years or less for all spacings and site indices.

Basal Area

Basal area increase is nearly linear with age for Site Indices 60 and below, but becomes increasingly curvilinear above Site Index 60. By 30 years net basal area accumulated on Site Indices 100 and 120 are similar and have nearly reached their maximum of about 280 square feet per acre (64 m^2/ha). Maximum basal area accumulated by 40 years on Site Index 80 but required more than 50 years on poorer sites. Basal area differences among spacings are small compared with those differences among site indices and age.

Cubic Volume

With increasing age and site index, net cubic volume increases nearly linearly. Similar to basal area, volume differences among spacings are less than those among ages and site indices. Only at older ages on better sites are volume differences among spacings large. The model predicts less volume as spacing becomes closer (*Appendix, tables 5-9*), suggesting volume growth stagnation beyond 30 years on Site Indices 80 and better. Periodic annual increment culminates at older ages for plantations spaced wider and at younger ages for plantations on better sites.

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APPENDIX

Table 5.
Yields of unthinned ponderosa pine plantations in northern California (Site Index 40)

Age from planting (years)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft^2)	Total net volume/acre (ft^3)
10	6 x 6	1028	4	0.4	1	26
	8 x 8	579	5	0.5	1	15
	10 x 10	370	5	0.6	1	10
	12 x 12	257	5	0.7	1	7
15	6 x 6	1028	8	1.5	13	79
	8 x 8	579	8	1.9	12	59
	10 x 10	370	8	2.2	10	47
	12 x 12	257	8	2.6	9	40
20	6 x 6	1028	12	2.6	37	200
	8 x 8	579	13	3.2	32	166
	10 x 10	370	13	3.8	30	143
	12 x 12	257	13	4.4	27	127
25	6 x 6	1028	17	3.4	64	392
	8 x 8	579	17	4.2	57	342
	10 x 10	370	18	5.0	51	305
	12 x 12	257	18	5.8	47	278
30	6 x 6	1028	21	4.0	88	642
	8 x 8	579	22	5.0	78	578
	10 x 10	370	22	6.0	72	526
	12 x 12	257	23	6.8	67	485
35	6 x 6	1028	24	4.5	112	934
	8 x 8	579	25	5.7	101	860
	10 x 10	370	26	6.7	91	791
	12 x 12	257	26	7.7	84	733
40	6 x 6	1028	27	4.9	135	1252
	8 x 8	579	29	6.2	120	1172
	10 x 10	370	29	7.4	110	1084
	12 x 12	257	30	8.5	100	1008
45	6 x 6	1028	30	5.2	153	1585
	8 x 8	579	32	6.7	141	1500
	10 x 10	370	33	7.9	127	1393
	12 x 12	257	33	9.1	116	1298
50	6 x 6	1028	32	5.5	172	1922
	8 x 8	579	35	7.1	158	1836
	10 x 10	370	36	8.4	143	1709
	12 x 12	257	36	9.7	132	1595

Table 6.
Yields of unthinned ponderosa pine plantations in northern California (Site Index 60)

Age from planting (years)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft^2)	Total net volume/acre (ft^3)
10	6 x 6	1028	6	0.8	4	33
	8 x 8	579	6	1.1	4	23
	10 x 10	370	6	1.4	4	17
	12 x 12	257	6	1.6	3	14
15	6 x 6	1028	11	2.3	29	156
	8 x 8	579	12	2.9	26	127
	10 x 10	370	12	3.4	24	108
	12 x 12	257	12	3.9	22	96
20	6 x 6	1028	18	3.6	74	445
	8 x 8	579	19	4.5	65	392
	10 x 10	370	19	5.4	59	353
	12 x 12	257	20	6.1	53	323
25	6 x 6	1028	24	4.5	116	896
	8 x 8	579	26	5.7	103	830
	10 x 10	370	26	6.8	94	768
	12 x 12	257	27	7.8	86	713
30	6 x 6	1028	30	5.2	153	1469
	8 x 8	579	32	6.7	141	1405
	10 x 10	370	33	7.9	127	1323
	12 x 12	257	33	9.1	116	1240
35	6 x 6	1028	35	5.8	187	2117
	8 x 8	579	37	7.4	174	2073
	10 x 10	370	38	8.9	158	1974
	12 x 12	257	39	10.2	147	1861
40	6 x 6	1028	39	6.2	214	2804
	8 x 8	579	42	8.0	203	2794
	10 x 10	370	43	9.6	187	2681
	12 x 12	257	44	11.1	172	2538
45	6 x 6	1028	42	6.5	240	3502
	8 x 8	579	46	8.6	232	3539
	10 x 10	370	48	10.3	214	3415
	12 x 12	257	49	11.9	199	3243
50	6 x 6	966	45	6.8	246	4195
	8 x 8	579	50	9.0	258	4286
	10 x 10	370	52	10.9	240	4153
	12 x 12	257	54	12.6	223	3953

Table 7.
Yields of unthinned ponderosa pine plantations in northern California (Site Index 80)

Age from planting (inches)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft^2)	Total net volume/acre (ft^3)
10	6 x 6	1028	8	1.5	12	51
	8 x 8	579	8	1.9	11	40
	10 x 10	370	8	2.2	10	33
	12 x 12	257	8	2.6	9	29
15	6 x 6	1028	15	3.1	53	300
	8 x 8	579	16	3.9	48	257
	10 x 10	370	16	4.5	41	227
	12 x 12	257	16	5.2	38	207
20	6 x 6	1028	24	4.5	112	869
	8 x 8	579	25	5.6	100	803
	10 x 10	370	26	6.6	89	742
	12 x 12	257	26	7.7	82	690
25	6 x 6	1028	32	5.4	165	1700
	8 x 8	579	34	7.0	154	1656
	10 x 10	370	35	8.3	139	1577
	12 x 12	257	36	9.5	128	1488
30	6 x 6	1028	38	6.2	214	2685
	8 x 8	579	42	8.0	204	2718
	10 x 10	370	43	9.6	185	2642
	12 x 12	257	44	11.1	171	2523
35	6 x 6	991	44	6.7	241	3735
	8 x 8	579	48	8.8	245	3892
	10 x 10	370	50	10.6	227	3841
	12 x 12	257	52	12.3	211	3703
40	6 x 6	894	49	7.1	248	4793
	8 x 8	525	55	9.6	261	5108
	10 x 10	370	57	11.5	266	5098
	12 x 12	257	59	13.3	249	4952
45	6 x 6	812	53	7.5	250	5824
	8 x 8	471	61	10.2	265	6319
	10 x 10	339	63	12.3	280	6363
	12 x 12	257	65	14.2	282	6220
50	6 x 6	757	57	7.8	252	6810
	8 x 8	426	66	10.8	269	7497
	10 x 10	307	69	13.0	284	7603
	12 x 12	233	71	15.1	291	7472

Table 8.
Yields of unthinned ponderosa pine plantations in northern California (Site Index 100)

Age from planting (years)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft^2)	Total net volume/acre (ft^3)
10	6 x 6	1028	10	2.0	23	98
	8 x 8	579	10	2.6	21	82
	10 x 10	370	10	3.0	18	72
	12 x 12	257	11	3.5	17	66
15	6 x 6	1028	18	3.6	72	556
	8 x 8	579	19	4.5	63	490
	10 x 10	370	19	5.4	58	437
	12 x 12	257	20	6.1	53	401
20	6 x 6	1028	29	5.2	151	1484
	8 x 8	579	31	6.6	136	1418
	10 x 10	370	32	7.8	123	1325
	12 x 12	257	33	9.0	113	1241
25	6 x 6	1028	38	6.2	214	2670
	8 x 8	579	42	8.0	203	2719
	10 x 10	370	43	9.6	185	2640
	12 x 12	257	44	11.1	172	2527
30	6 x 6	942	46	6.9	246	3920
	8 x 8	570	51	9.1	258	4191
	10 x 10	370	53	11.0	244	4189
	12 x 12	257	54	12.7	226	4089
35	6 x 6	812	53	7.5	247	5131
	8 x 8	484	60	10.0	266	5697
	10 x 10	343	62	12.2	278	5823
	12 x 12	257	64	14.1	279	5775
40	6 x 6	758	58	7.8	255	6259
	8 x 8	419	68	10.9	271	7159
	10 x 10	298	71	13.2	285	7446
	12 x 12	227	73	15.4	292	7486
45	6 x 6	709	62	8.1	254	7288
	8 x 8	375	75	11.6	277	8540
	10 x 10	259	80	14.3	290	9009
	12 x 12	203	81	16.4	299	9161
50	6 x 6	679	66	8.3	255	8221
	8 x 8	329	83	12.5	279	9826
	10 x 10	225	90	15.5	295	10486
	12 x 12	185	89	17.2	301	10766

Table 9.
Yields of unthinned ponderosa pine plantations in northern California (Site Index 120)

Age from planting (years)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft^2)	Total net volume/acre (ft^3)
10	6 x 6	1028	13	2.8	42	228
	8 x 8	579	14	3.5	38	197
	10 x 10	370	14	4.1	34	174
	12 x 12	257	14	4.7	31	158
15	6 x 6	1028	23	4.3	106	997
	8 x 8	579	24	5.4	94	880
	10 x 10	370	25	6.5	84	773
	12 x 12	257	25	7.4	77	699
20	6 x 6	1028	34	5.7	184	2221
	8 x 8	579	37	7.4	172	2161
	10 x 10	370	38	8.8	158	2015
	12 x 12	257	39	10.2	145	1883
25	6 x 6	966	45	6.8	240	3473
	8 x 8	579	49	8.9	250	3670
	10 x 10	370	51	10.7	232	3605
	12 x 12	257	53	12.4	216	3494
30	6 x 6	812	53	7.5	250	4572
	8 x 8	471	61	10.2	266	5151
	10 x 10	336	63	12.3	277	5274
	12 x 12	257	65	14.2	282	5274
35	6 x 6	725	60	8.0	254	5487
	8 x 8	393	71	11.2	271	6500
	10 x 10	278	75	13.7	286	6877
	12 x 12	215	77	15.9	296	7060
40	6 x 6	694	65	8.1	251	6241
	8 x 8	343	81	12.2	279	7693
	10 x 10	235	86	15.1	291	8355
	12 x 12	185	88	17.3	303	8768

Table 10. Mean diameters and number of trees by crown classes for unthinned ponderosa pine plantations in northern California (Site Index 40)

Age from planting (years)	Planted spacing (ft)	Mean d.b.h. when crown class is D	C	I	S	Trees per acre when crown class is D	C	I	S
		inches				number			
10	6 x 6	0.5	0.0	0.0	0.0	519	390	114	5
	8 x 8	0.6	0.0	0.0	0.0	342	220	16	1
	10 x 10	0.7	0.0	0.0	0.0	240	129	1	0
	12 x 12	0.8	0.0	0.0	0.0	180	77	0	0
15	6 x 6	1.8	1.4	1.0	0.0	428	388	196	16
	8 x 8	2.2	1.7	1.1	0.0	294	220	61	4
	10 x 10	2.5	1.9	1.3	0.0	215	140	14	1
	12 x 12	2.8	2.2	1.5	0.0	162	91	4	0
20	6 x 6	3.0	2.6	2.1	0.7	350	355	290	33
	8 x 8	3.6	3.1	2.5	0.8	250	214	106	9
	10 x 10	4.2	3.6	2.8	0.9	189	141	38	2
	12 x 12	4.7	4.0	3.2	1.0	145	98	13	1
25	6 x 6	4.0	3.5	2.9	1.2	292	339	344	53
	8 x 8	4.8	4.2	3.5	1.4	220	208	137	14
	10 x 10	5.6	4.8	4.0	1.6	160	139	67	4
	12 x 12	6.3	5.4	4.4	1.8	131	98	26	2
30	6 x 6	4.7	4.2	3.5	1.6	257	325	374	72
	8 x 8	5.7	5.0	4.2	1.9	198	203	160	18
	10 x 10	6.7	5.8	4.8	2.1	152	136	75	7
	12 x 12	7.5	6.5	5.4	2.3	123	97	35	2
35	6 x 6	5.4	4.8	4.0	1.9	231	310	397	90
	8 x 8	6.6	5.7	4.8	2.2	182	197	177	23
	10 x 10	7.6	6.6	5.5	2.4	144	130	87	9
	12 x 12	8.6	7.4	6.1	2.7	116	96	41	4
40	6 x 6	6.0	5.3	4.5	2.1	211	295	413	109
	8 x 8	7.2	6.3	5.3	2.4	170	194	187	28
	10 x 10	8.4	7.3	6.1	2.7	137	132	91	10
	12 x 12	9.5	8.1	6.8	3.0	110	95	48	4
45	6 x 6	6.5	5.8	4.8	2.3	189	284	428	127
	8 x 8	7.9	6.9	5.8	2.6	161	190	196	32
	10 x 10	9.1	7.9	6.6	3.0	129	131	99	11
	12 x 12	10.3	8.8	7.3	3.3	106	94	52	5
50	6 x 6	7.0	6.2	5.2	2.4	173	274	435	146
	8 x 8	8.4	7.4	6.2	2.8	152	185	206	36
	10 x 10	9.8	8.4	7.0	3.2	124	129	105	12
	12 x 12	11.0	9.4	7.9	3.5	102	94	56	5

Table 11. Mean diameters and number of trees by crown classes for unthinned ponderosa pine plantations in northern California (Site Index 60)

Age from planting (years)	Planted spacing (ft)	Mean d.b.h. when crown class is D	C	I	S	Trees per acre when crown class is D	C	I	S
		inches				number			
10	6 x 6	1.1	0.6	0.0	0.0	447	380	186	15
	8 x 8	1.4	0.8	0.0	0.0	309	223	44	3
	10 x 10	1.6	0.9	0.0	0.0	223	139	8	0
	12 x 12	1.8	1.0	0.0	0.0	166	91	0	0
15	6 x 6	2.7	2.3	1.8	0.5	350	360	287	31
	8 x 8	3.2	2.8	2.2	0.6	255	215	101	8
	10 x 10	3.8	3.2	2.5	0.7	190	141	36	3
	12 x 12	4.2	3.6	2.8	0.8	146	98	12	1
20	6 x 6	4.3	3.8	3.1	1.4	278	333	357	60
	8 x 8	5.2	4.5	3.7	1.6	210	206	147	16
	10 x 10	6.0	5.2	4.3	1.8	161	137	66	6
	12 x 12	6.7	5.8	4.8	2.0	126	98	31	2
25	6 x 6	5.5	4.9	4.1	1.9	223	306	401	98
	8 x 8	6.6	5.8	4.9	2.2	179	197	179	24
	10 x 10	7.7	6.8	5.6	2.5	142	133	87	8
	12 x 12	8.7	7.5	6.2	2.7	114	96	44	3
30	6 x 6	6.5	5.8	4.8	2.3	190	286	426	126
	8 x 8	7.9	6.9	5.8	2.6	161	190	196	32
	10 x 10	9.1	7.9	6.6	3.0	129	130	100	11
	12 x 12	10.3	8.8	7.3	3.3	105	94	53	5
35	6 x 6	7.4	6.5	5.5	2.6	159	265	442	162
	8 x 8	8.9	7.8	6.5	3.0	145	182	211	41
	10 x 10	10.4	8.9	7.4	3.4	118	127	111	14
	12 x 12	11.7	10.0	8.3	3.7	98	93	60	6
40	6 x 6	8.1	7.1	6.0	2.8	138	247	449	194
	8 x 8	9.8	8.5	7.1	3.3	133	176	221	49
	10 x 10	11.4	9.8	8.1	3.7	111	125	117	17
	12 x 12	12.8	10.9	9.1	4.1	92	91	67	7
45	6 x 6	8.8	7.7	6.5	3.0	118	228	456	226
	8 x 8	10.6	9.2	7.7	3.5	123	171	229	56
	10 x 10	12.3	10.5	8.8	4.0	104	122	125	19
	12 x 12	13.9	11.8	9.8	4.4	88	90	71	8
50	6 x 6	9.4	8.2	6.9	3.2	99	201	429	237
	8 x 8	11.3	9.8	8.2	3.8	115	166	234	64
	10 x 10	13.1	11.2	9.4	4.3	100	120	128	22
	12 x 12	14.8	12.6	10.4	4.7	84	89	75	9

Table 12. Mean diameters and number of trees by crown classes for unthinned ponderosa pine plantations in northern California (Site Index 80)

Age from planting (years)	Planted spacing (ft)	Mean d.b.h. when crown class is D	C	I	S	Trees per acre when crown class is D	C	I	S
		inches				number			
10	6 x 6	1.8	1.4	1.0	0.0	397	370	238	23
	8 x 8	2.2	1.7	1.2	0.0	278	219	76	6
	10 x 10	2.5	1.9	1.4	0.0	206	142	21	1
	12 x 12	2.8	2.2	1.5	0.0	154	97	6	0
15	6 x 6	3.6	3.2	2.6	1.1	305	346	330	47
	8 x 8	4.4	3.9	3.1	1.2	226	210	131	12
	10 x 10	5.0	4.3	3.6	1.4	168	139	59	4
	12 x 12	5.7	4.9	4.0	1.5	133	98	24	2
20	6 x 6	5.4	4.8	4.0	1.8	233	311	394	90
	8 x 8	6.5	5.7	4.8	2.2	182	198	176	23
	10 x 10	7.5	6.5	5.4	2.4	144	134	84	8
	12 x 12	8.5	7.3	6.1	2.7	116	96	42	3
25	6 x 6	6.8	6.0	5.1	2.4	178	277	433	140
	8 x 8	8.3	7.2	6.1	2.8	155	186	203	35
	10 x 10	9.6	8.3	6.9	3.1	125	129	104	12
	12 x 12	10.8	9.3	7.7	3.5	102	94	56	5
30	6 x 6	8.1	7.1	6.0	2.8	139	247	449	193
	8 x 8	9.8	8.5	7.1	3.3	134	177	221	47
	10 x 10	11.3	9.7	8.1	3.7	111	125	117	17
	12 x 12	12.8	10.9	9.0	4.1	92	91	67	7
35	6 x 6	9.1	7.9	6.7	3.1	108	214	440	229
	8 x 8	11.0	9.5	7.9	3.7	119	168	232	60
	10 x 10	12.7	10.9	9.1	4.1	102	121	126	21
	12 x 12	14.4	12.2	10.1	4.6	85	89	75	8
40	6 x 6	10.0	8.7	7.3	3.4	81	175	399	239
	8 x 8	12.1	10.4	8.7	4.0	100	147	217	61
	10 x 10	14.0	11.9	9.9	4.5	95	118	132	25
	12 x 12	15.8	13.3	11.1	5.0	81	88	78	10
45	6 x 6	10.8	9.3	7.9	3.7	61	147	363	241
	8 x 8	13.0	11.2	9.3	4.3	84	128	200	59
	10 x 10	15.1	12.8	10.7	4.8	83	106	126	24
	12 x 12	17.0	14.3	11.9	5.3	76	86	83	12
50	6 x 6	11.5	9.9	8.4	3.9	49	124	336	248
	8 x 8	13.9	11.9	9.9	4.5	71	115	186	54
	10 x 10	16.1	13.6	11.3	5.1	74	95	116	22
	12 x 12	18.2	15.2	12.7	5.6	68	78	78	9

Table 13. Mean diameters and number of trees by crown classes for unthinned ponderosa pine plantations in northern California (Site Index 100)

Age from planting (years)	Planted spacing (ft)	Mean d.b.h. when crown class is D	C	I	S	Trees per acre when crown class is D	C	I	S
		inches				number			
10	6 x 6	2.4	2.0	1.6	0.2	358	361	277	32
	8 x 8	2.9	2.4	1.9	0.2	259	215	97	8
	10 x 10	3.3	2.8	2.1	0.2	190	141	36	3
	12 x 12	3.8	3.1	2.4	0.2	148	98	11	0
15	6 x 6	4.2	3.8	3.1	1.4	268	330	365	65
	8 x 8	5.1	4.5	3.7	1.6	204	204	154	17
	10 x 10	6.0	5.2	4.3	1.8	157	136	71	6
	12 x 12	6.7	5.8	4.7	2.0	126	97	32	2
20	6 x 6	6.4	5.7	4.8	2.2	195	288	423	122
	8 x 8	7.7	6.8	5.7	2.6	162	190	196	31
	10 x 10	9.0	7.7	6.5	2.9	130	130	99	11
	12 x 12	10.1	8.7	7.2	3.2	107	95	50	5
25	6 x 6	8.1	7.1	6.0	2.8	139	247	450	192
	8 x 8	9.8	8.5	7.1	3.3	134	177	220	48
	10 x 10	11.3	9.7	8.1	3.7	111	125	117	17
	12 x 12	12.8	10.9	9.1	4.1	93	91	66	7
30	6 x 6	9.5	8.3	7.0	3.3	96	196	417	233
	8 x 8	11.4	9.9	8.3	3.8	112	162	233	63
	10 x 10	13.3	11.3	9.5	4.3	98	120	130	22
	12 x 12	15.0	12.7	10.5	4.7	83	89	75	10
35	6 x 6	10.7	9.3	7.8	3.6	63	150	363	236
	8 x 8	12.9	11.0	9.2	4.2	86	133	205	60
	10 x 10	14.9	12.7	10.6	4.8	84	108	127	24
	12 x 12	16.9	14.2	11.8	5.3	77	87	81	12
40	6 x 6	11.7	10.1	8.5	3.9	46	119	337	256
	8 x 8	14.1	12.0	10.1	4.6	70	110	185	54
	10 x 10	16.4	13.8	11.5	5.2	70	93	114	21
	12 x 12	18.5	15.5	12.8	5.7	67	73	78	9
45	6 x 6	12.6	10.8	9.1	4.2	33	95	307	274
	8 x 8	15.2	13.0	10.8	4.9	56	99	171	49
	10 x 10	17.7	14.9	12.5	5.6	60	81	102	16
	12 x 12	19.9	16.6	13.8	6.1	58	62	76	7
50	6 x 6	13.4	11.5	9.7	4.4	19	79	289	292
	8 x 8	16.2	13.8	11.5	5.2	49	88	156	36
	10 x 10	18.8	15.8	13.1	5.9	55	73	96	1
	12 x 12	21.2	17.7	14.6	6.5	50	52	76	7

Table 14. Mean diameters and number of trees by crown classes for unthinned ponderosa pine plantations in northern California (Site Index 120)

Age from planting (years)	Planted spacing (ft)	Mean d.b.h. when crown class is D	C	I	S	Trees per acre when crown class is D	C	I	S
		inches				number			
10	6 x 6	3.2	2.8	2.3	0.9	329	354	306	39
	8 x 8	3.9	3.4	2.7	1.0	241	212	116	10
	10 x 10	4.5	3.9	3.1	1.1	181	140	46	3
	12 x 12	5.1	4.3	3.5	1.3	140	98	18	1
15	6 x 6	5.2	4.6	3.9	1.8	241	315	388	84
	8 x 8	6.3	5.5	4.6	2.1	188	200	170	21
	10 x 10	7.3	6.3	5.2	2.3	148	135	80	7
	12 x 12	8.2	7.1	5.8	2.6	117	96	41	3
20	6 x 6	7.3	6.5	5.4	2.5	162	275	431	160
	8 x 8	8.9	7.7	6.5	3.0	146	183	209	41
	10 x 10	10.3	8.9	7.4	3.4	120	128	108	14
	12 x 12	11.6	9.9	8.3	3.7	99	93	59	6
25	6 x 6	9.2	8.0	6.8	3.2	103	207	428	228
	8 x 8	11.1	9.6	8.1	3.7	117	167	232	63
	10 x 10	12.9	11.0	9.2	4.2	101	121	127	21
	12 x 12	14.6	12.3	10.3	4.6	85	89	74	9
30	6 x 6	10.8	9.3	7.9	3.7	61	147	363	241
	8 x 8	13.0	11.2	9.3	4.3	86	129	197	59
	10 x 10	15.1	12.8	10.7	4.8	82	105	125	24
	12 x 12	17.0	14.3	11.9	5.3	76	86	83	12
35	6 x 6	12.1	10.5	8.8	4.1	37	110	317	261
	8 x 8	14.6	12.5	10.4	4.8	63	103	175	52
	10 x 10	17.0	14.3	11.9	5.4	66	86	107	19
	12 x 12	19.2	16.0	13.3	5.9	63	67	77	8
40	6 x 6	13.2	11.4	9.5	4.4	21	80	290	303
	8 x 8	16.0	13.6	11.3	5.2	51	90	158	44
	10 x 10	18.6	15.6	13.0	5.8	54	74	96	11
	12 x 12	21.0	17.5	14.5	6.4	51	62	66	6

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1978. **Growth models for ponderosa pine: I. Yield of unthinned plantations in northern California.** Res. Paper PSW-133, 21 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

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Oxford: 174.7 *Pinus ponderosa* — 566[+612]

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