

DEVELOPING STAND DENSITY GUIDES FOR PREDICTING GROWTH OF TIMBER SPECIES ON THE SALMON NATIONAL FOREST, IDAHO

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ABSTRACT

This paper presents a method for estimating the growing space required by trees of given diameters to maintain a specific rate of diameter growth at breast height. Growth data were derived by increment-coring Douglas fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and lodgepole pine (*Pinus contorta*) stands throughout their range on the Salmon National Forest in central Idaho. The model accurately predicted 20-year diameter growth on ponderosa pine growth plots in three locations in the western United States.

Keywords: Douglas-fir, ponderosa pine, lodgepole pine, spacing guides, diameter growth, central Idaho

INTRODUCTION

Stand density is an important consideration in timber management. Although easily manipulated, stand density affects all the products and uses of a forest. Until recently, foresters on the Salmon National Forest in east-central Idaho have not had reliable stocking guides for their dominant timber-producing species. Past thinning efforts usually have not created enough growing space, or the thinning was delayed so long that the trees had small crowns and could not respond to the thinning treatment as predicted by the stocking guides. Relative Stand Density Index (Drew and Flewelling 1979) and Reineke's Stand Density Index (Reineke 1933; Gingrich 1967) provide useful formats but do not show how to choose density levels to meet specific management objectives. Ideally, the relationship between stand density and growth is established through repeated measurements over time in permanent sample plots at a variety of sites and at several density levels. Unfortunately it takes many years before such research produces results. Meanwhile, foresters must continue to decide stand densities, often relying on experience and extrapolations from published data of questionable relevance to the timber stands at hand. Large errors in stocking density cannot be easily corrected; moreover, such errors can result in costly losses in timber production. For these reasons the Intermountain Region of the Forest Service, U.S. Department of Agriculture supported an administrative study in the Salmon National Forest, to develop stocking guides that could quickly be implemented for ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), and Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco). Assuming that other forest managers face the same predicament, in this article the authors describe the development and application of their stocking guides.

METHODS

General Procedure

Our approach to developing stocking guides was based on evidence that to achieve reasonable growth from many forest sites in the Intermountain Region we must maintain a more uniform spacing between crop trees than we have in the past. Basal area and/or trees-per-acre measures, by themselves, average different diameter sizes and densities over the total area included within the stand boundaries. The result is that densities can remain higher than desired in parts of the stand even after thinning. This is not a serious problem on the best sites because trees are capable of growing at a reasonable though reduced rate. But on the poor-to-average sites this usually results in little or almost no stand response after thinning. This conclusion is supported by data collected from thinned stands on the Salmon, Targhee, and Dixie National Forests. In dbh classes between 5 and 14 inches, there has been little growth response to thinning because spacings were usually too narrow.

The growth equations developed on the Salmon National Forest were derived from the analysis of increment cores rather than from the traditional measurement of permanent sample plots. In this way, data was obtained in a shorter time. Trees of various sizes, spacings, and habitat types were sought for measurements of diameter growth rates, distance to adjacent trees, and crown ratio. Individual sample trees were selected that were surrounded by trees with relatively even spacing and uniform diameters. In other words, it was important that individual sample trees had experienced consistent competition on all four sides since the sample tree came into competition with surrounding trees. All sample trees had to be free from mortality and from insect and disease attacks. Thus, one could reasonably assume that reductions in growth rates were related to spacing. On increment cores, we observed that trees starting out with adequate growing space in a uniformly spaced, even-aged stand have identifiable periods when the growth rates are relatively constant. As the trees grow larger and competition begins, the transitions between periods are abrupt enough to be discerned on an increment core. We identified three of these growth reduction points which define four "growth periods."

The maximum growth rates that can be expected vary by tree size, species, and site quality, even when growing space is more than adequate. To determine those upper limits we sampled mature and over-mature trees which showed no evidence of current or past competitive stress. Increment core analyses of these "free-to-grow" trees also showed periods of relatively uniform diameter growth and points of identifiable reductions in growth similar to the trees that had been under competition. However, these reductions were due to tree physiology and occurred at larger diameters than trees under competition.

Growing Space and Growth Rates

The following is a detailed description of the procedures used for determining growth rates of trees at different size and spacings in ponderosa pine, lodgepole pine, and Douglas-fir:

1. Select stands with a relatively narrow range of tree diameters located on the habitat types of interest. Locate enough samples for a good range of diameters and spacing.
2. Within each stand select sample trees such that the diameter differences between the sample tree and adjacent competing trees do not exceed one third of the diameter of the sample tree (Figure 1), (e.g., if the sample tree dbh is 9 inches, diameter of adjacent tree should be between 6 and 12 inches.)

Distance to each adjacent tree should not exceed one-third of the average distance between the sample tree and adjacent trees.

There should be a least four adjacent competing trees and none of the four angles between the sample tree and adjacent trees should exceed 120 degrees.

Disregard trees one inch dbh or smaller if they are located well within the influence of larger adjacent trees and are judged incapable of influencing the growth of the sample tree. This type of tree is not considered a competing tree and is not used in the spacing calculations.

3. Take increment cores from the uphill and downhill side of each sample tree. Measure the radial distance from the pith to the end of each identified growth period (Figure 2), and add them to get the diameter inside bark (DBHib). Determine the diameter outside bark (DBHob) at each point using the following equation:

$$DBHob = K(DBHib)$$

where: K^3 , Douglas-fir = 1.11
 K , Ponderosa pine = 1.15
 K , Lodgepole pine = 1.05

$${}^2K = \frac{E DBHob}{E DBHib} \quad \text{as described by Husch } et al. \text{ 1972.}$$

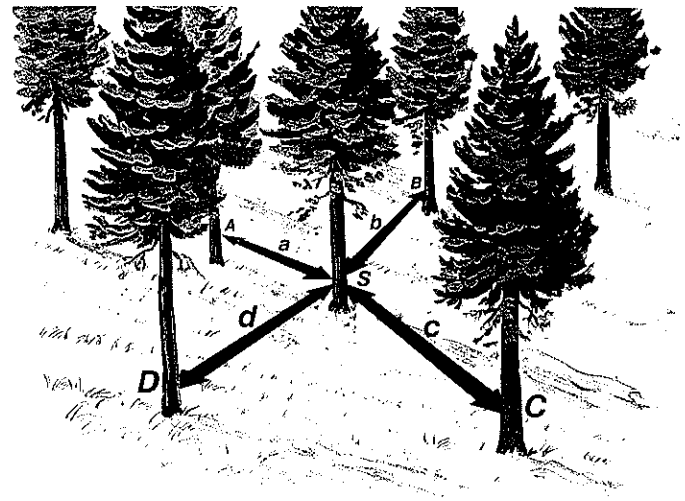


Figure 1. — Size and distribution of sample tree (S) and adjacent trees. Each distance (a, b, c, and d) should be within one-third of the average distance between the sample trees and adjacent trees (A, B, C, and D). The diameters of A, B, C, and D should be within one-third of the dbh of S. All trees must be disease and insect free, and the stand should not have suffered any mortality within the plot boundary.

4. Calculate average number of rings per inch (RPI) for each growth period by dividing the number of rings by the length of core within that period. Average the measurements from the two cores. Reject samples that show growth rates during the first growth period that are not within 3 rings of the potential rate for the site as indicated by free-to-grow trees. If the growth rate was less than the recommended variance, it was probably due to an unidentified cause such as nearby trees that have since disappeared.
5. For each sample tree the following data is needed: Species, dbh, total tree height, crown ratio, age at dbh, RPI and DBHib for each growth period (as described in step 3 and

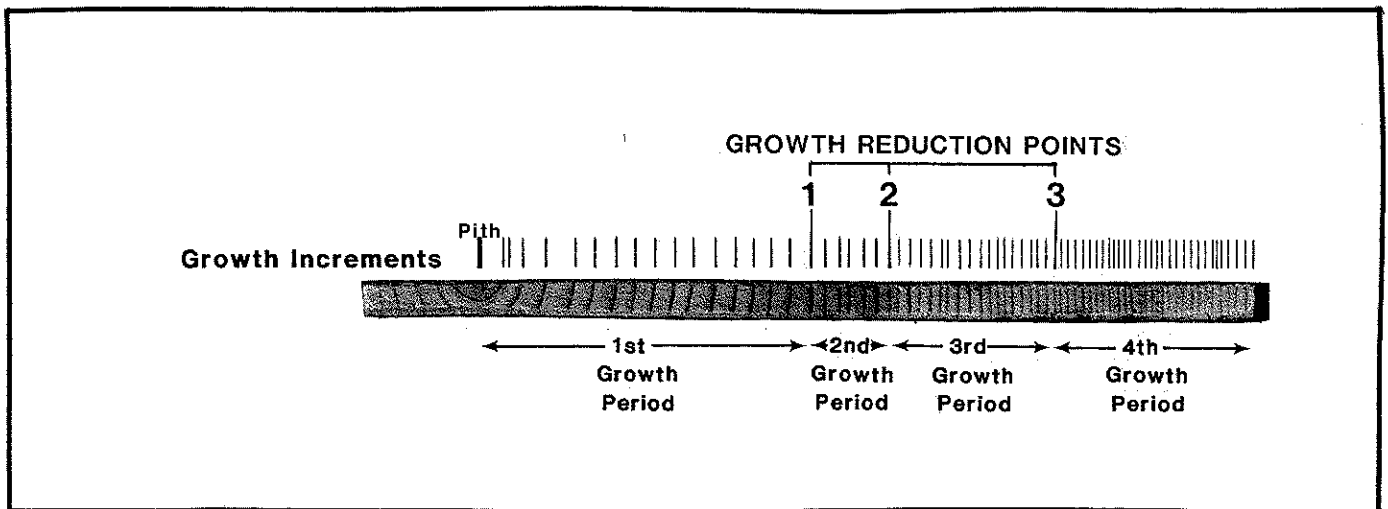


Figure 2. — Typical sample core, delineating growth rates, periods of uniform growth, and points at which growth reductions occur. Rings per inch (RPI) are computed for each growth period.

- 4), distance to the edge of the crown of the sample tree (crown radius), distance to the edge of the adjacent tree crown, total distance between the bole of the sample tree to the bole of each adjacent tree, and azimuth to each adjacent tree.
6. For each species with similar habitat type and site quality, graph the average distance between the boles of the sample tree and adjacent trees against DBHob from step 3 (Figure 2). Compute and draw a linear regression line for the transition points between each growth period (Figure 3).

For each growth period, show the average rings per inch of all sample trees. For all regressions, plots of residuals versus predicted values were examined, and standard deviations about the regressions were calculated as measures of reliability (Figure 4).

Growth Rates of Free-To-Grow Trees

A second group of trees that showed no sign of intertree competition, past or present, was also sampled. Analysis of these "free-to-grow" trees also showed periods of uniform diameter growth and reduction points similar to the trees in competition. But the growth reductions occurred at larger diameters since the trees were not under competition and they appeared to be related only to tree size.

In addition to site characteristics, the following measurements were made on each free-to-grow sample tree: species, diameter at breast height (dbh), height, live crown ratio and width, age, and rings-per-inch for each growth period. Increment cores and bark thickness from both uphill and downhill sides were taken

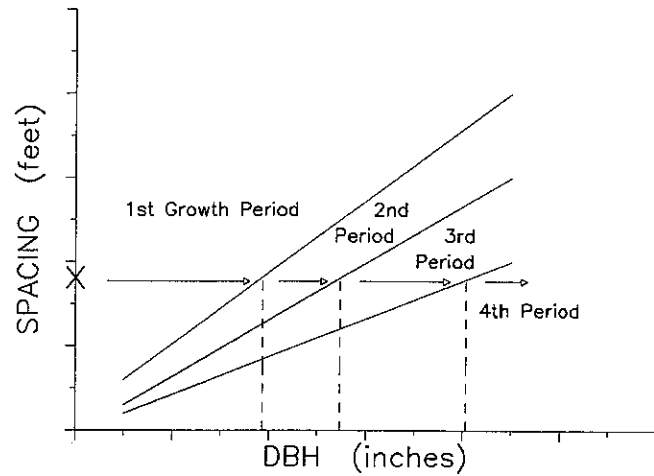


Figure 3.—Spacing or competition lines. Area between lines represents uniform growth periods. At "X", spacing a tree will progress horizontally across the chart passing through the uniform growth periods.

from each sample tree to verify growth periods, and measurements were averaged.

The data from the free-to-grow trees were used in three ways: 1) to determine the potential diameter growth rates in the absence of intertree competition. These data are used in step 4 as described in the previous section, Growing Space and Growth Rates; 2) to determine the average diameters at which growth reductions occur for each species and habitat type (Table 1); and 3) to determine how long after thinning a stand can

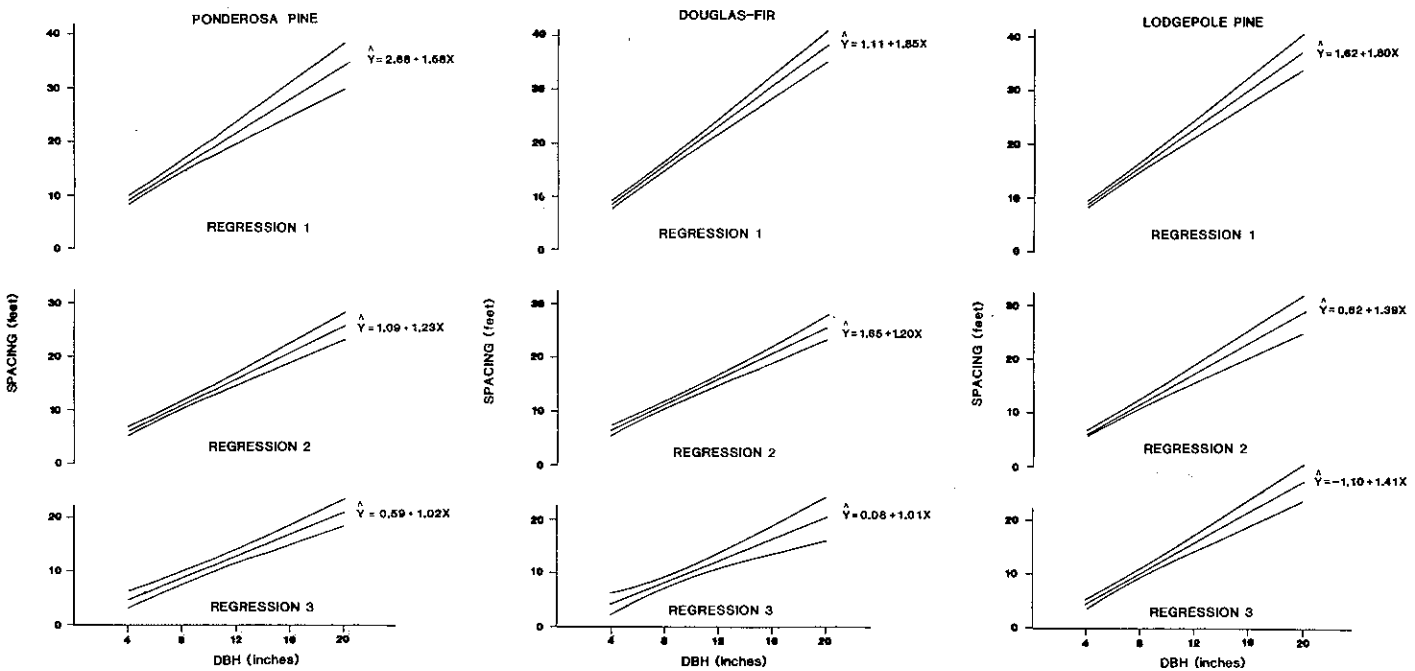


Figure 4.—Confidence intervals (95%) for the spacing/dbh regressions (Table 2) for Douglas-fir (Figure 5), ponderosa pine (Figure 6), and lodgepole pine (Figure 7).

Table 1. — Mean diameter growth rates during each period and the mean dbh at the end of each growth period for open-grown trees. Site indexes (100) sources: Douglas-fir, Brickell (1968), converted to a 100-year base age; ponderosa pine, Meyer (1938); lodgepole pine, Alexander (1966).

Ranger District	Species	Habitat type	Average site index of 100-yr base age	Number of trees in sample	Growth rate before reduction (RPI)	dbh at growth reduction point (in.)	Growth rate between first and second reduction (RPI)	dbh at second reduction (in.)	Growth rate between second and third reduction (RPI)	dbh at third reduction (in.)	Growth rate after third reduction (RPI)
North Fork	Douglas-fir	Psme/Caru-Pipo	98	3	8.1	20.5	13.7	28.5	23.9	30.6	44.6
	Ponderosa pine	Psme/Caru-Pipo	79	5	6.6	13.6	10.9	20.1	16.8	25.8	22.1
		Psme/Cage-Pipo	77	3	8.8	12.6	13.7	19.2	23.0	—	—
		Psme/Syal-Pipo	87	3	7.6	13.2	13.7	20.0	21.6	26.1	26.8
		Average for all sites	81	—	7.5	13.2	12.4	19.8	19.8	—	—
Salmon	Douglas-fir	Psme/Feid-Feid	65	4	9.2	12.8	16.3	21.9	21.2	—	—
		Psme/Caru-Feid and/Caru-Caru	75	4	7.8	16.4	10.8	26.6	17.0	33.2	29.2
	Lodgepole pine	Psme/Caru-Caru	74	6	7.1	9.5	11.8	—	—	—	—
Leadore	Douglas-fir	Psme/Caru-Caru	58	3	8.9	11.5	12.4	18.3	25.9	—	—

maintain a certain growth rate before the stand again experiences intertree competition. For example: a Douglas-fir stand commercially thinned at a 13 inch dbh on the Leadore Ranger District will not respond at 8.9 rings per inch, but instead will grow at 12.4 rings per inch because the stand has passed the first growth reduction point of the free-to-grow trees at 11.5 dbh (Table 1). However, on a more productive site on the North Fork Ranger District, a stand commercially thinned at 13 inches will respond at 8.1 rings per inch until it reaches the first growth reduction point of the free-to-grow trees at 20.5 inch dbh or until the stand comes back into intertree competition (Figure 5).

Finally, for ponderosa pine and Douglas-fir, crown ratios between 20% and 90% were plotted against growth rates of trees free from competition and from silvicultural treatment. Because the ponderosa pine and Douglas-fir curves were so similar, the data were combined to make one curve.

Our growth rate equations represent an attempt to more closely model the way in which tree growth has been observed in the field. In other words, our method is based on individual tree growth rather than on net growth of the whole stand.

RESULTS AND DISCUSSION

The criteria for locating sample trees under competition made it difficult to find a large number of trees in some diameter ranges. Large trees and trees smaller than 3 inches dbh were especially rare. Generally, sample trees were easier to find on drier sites where initial spacings are usually wider than on moist sites.

From the free-to-grow trees, the dbh at each growth reduction point and growth rates for the different growth periods were tabulated by species and habitat type (Table 1). On all Salmon National Forest sites growth rate for ponderosa pine first

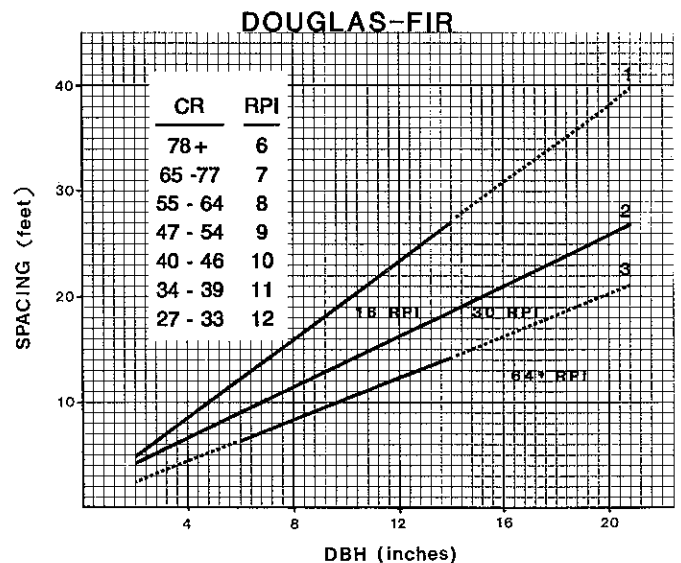


Figure 5. — Diameter growth rates (rings-per-inch) associated with spacing and tree size of Douglas-fir. Confidence intervals for each regression are depicted in Figure 4. Equations for each regression are presented in Table 2. The diameter growth rate before the first regression line (first growth period) depends on the crown ratio. Between the first and second regression lines (second growth period) the growth rate is 16 rings per inch, between the second and third regression lines (third growth period) 30 RPI and after the third regression line (fourth growth period) 64 RPI.

changes at approximately 13.2 inches dbh. Growth slows from about 7.5 to 12.4 rings per inch. The second growth-reduction point is at 19.8 inches when the growth rate slows to 19.8 rings per inch.

For Douglas-fir, the dbh at the first growth rate reduction varies by site, but the greatest average growth rates during the

Table 2.—Tree spacing and dbh regression equations for Douglas-fir, ponderosa pine, and lodgepole pine on the Salmon National Forest. Regression equations represent the transitions between the maximum average growth rates. The independent variable, X, is the tree dbh. The dependent variable, Y, is tree spacing.

Species	Maximum ave. growth rate (RPI)	Sample size	Range of data (dbh, in.)	Equations	r ²
Douglas-fir	8 ^a	25	1-13	Y = 2.68+1.58X	0.86
	16	21	2-16	Y = 1.09+1.23X	0.91
	32	8	4-21	Y = 0.59+1.02X	0.96
Ponderosa pine	8 ^b	36	2-14	Y = 1.11+1.85X	0.91
	16	29	2-21	Y = 1.65+1.20X	0.89
	30	7	6-14	Y = 0.08+1.01X	0.92
Lodgepole pine	9	39	2-12	Y = 1.63+1.80X	0.90
	19	37	2-11	Y = 0.62+1.39X	0.81
	35	22	3-13	Y = -1.10+1.41X	0.89

a This value is further divided in Figure 6 according to crown ratio. The crown ratio/growth rate regression (Figure 4) can also be used to estimate this value.

b This value is further divided in Figure 3 according to crown ratio. The crown ratio/growth rate regression (Figure 4) can also be used to estimate this value.

first period are about 8-9 rings per inch (Table 1). The lodgepole pine growth rate drops from 7.1-11.8 rings per inch at 9.5 inch dbh. The number of trees sampled in each habitat type are too few to express confidence in the mean. Site indexes in Table 1 are higher than the Salmon National Forest timber inventory shows for similar sites because most of the inventory site trees have had competition.

Table 2 shows tree spacing and dbh regression equations for ponderosa pine, Douglas-fir, and lodgepole pine. In each, the independent variable, X, is the dbh and the dependent variable, Y, is the spacing. These equations are plotted in Figures 5, 6, and 7. Confidence intervals for all of the regressions are depicted in Figure 4. The ponderosa pine graph (Figure 6) is similar to the Douglas-fir graph (Figure 5). For both, the diameter growth rate before the first regression line depends on the crown ratio. Figure 8 can also be used to estimate ponderosa pine and Douglas-fir growth rates in the first period based on crown ratios. The diameter growth rate between the first and second regression lines is 16 rings per inch for both species. The third growth rate is 32 rings per inch between the second and third regression lines for ponderosa pine and 30 for Douglas-fir. After the third regression line, diameter growth falls to 55 rings for ponderosa pine and 64 rings for Douglas-fir. For lodgepole pine, the growth rates are 9, 19, 35, and 63 rings per inch (Figure 7).

Another finding as expected, was that average crown ratios were related to dbh and tree spacing. Table 3 shows spacing vs. dbh regression equations for several crown ratio groups by species. The r² values range from 0.52 up to 0.90. The data came from trees under competition.

Finally, in order to predict how a stand will respond when thinned to a competition-free spacing, the relationship between growth rate and crown ratio was plotted for ponderosa pine and Douglas-fir trees free from competition. Because the curves for the two species were so similar, the data were combined to form one curve (Figure 8). The r² of this exponential regression is 0.59. Data were not available to construct a relationship of crown ratio to growth rate for lodgepole pine, but this curve would probably be similar to the one in Figure 8.

Table 3.—Equations for spacing/dbh for different crown ratio groups, Salmon National Forest. The independent variable, X, is the tree dbh. The dependent variable, Y, is tree spacing.

Species	Crown ratio (percent)	Equations	R ²
Douglas-fir	60	Y = 1.86+1.15X	0.85
	50	Y = 1.42+0.98X	0.79
	40	Y = 0.89+0.94X	0.68
	30	Y = 1.78+0.74X	0.78
Ponderosa pine	40 & 50	Y = -0.27+1.05X	0.90
	30	Y = -0.97+0.99X	0.86
Lodgepole pine	50, 60 & 70	Y = -0.39+1.32X	0.52
	30 & 40	Y = -1.26+1.26X	0.65

On the Salmon National Forest, Douglas-fir occurs over a greater range of elevation and habitat types than ponderosa pine and lodgepole pine. Because growth reduction occurs at a lower dbh on poorer sites in free-to-grow trees, there is more variability for Douglas-fir than for the other species (Table 1). Growth rates before the first reduction line do not vary widely between species or sites. On three habitat types for ponderosa pine, five for Douglas-fir, and one for lodgepole pine, average growth rates for the first growth period range from 7-9 rings per inch.

The regression equations in Table 2 represent the transitions between growth periods. Equations have been developed for three growth periods per species. The predictive abilities of these equations are consistently high, with only two r² values below 0.89.

The data on which these equations are based came from trees ranging in size from 1-21 inch dbh. As can be seen in the confidence interval widths (Figure 4), most of the sample trees were in the 4- to 12-inch dbh range. The user must be careful not to extrapolate beyond the range of the independent variable because these are empirically derived equations. Extrapolation beyond the range of the data may lead to gross errors in estimation.

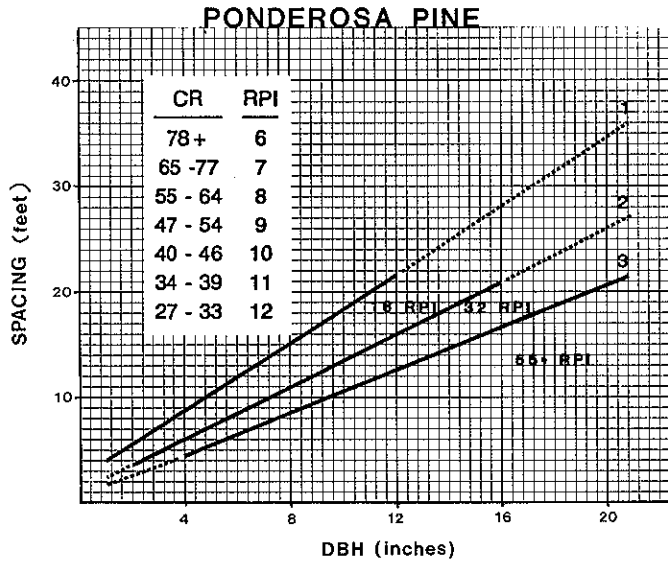


Figure 6. — Diameter growth rates (rings per inch) associated with spacing and tree size of ponderosa pine. Confidence intervals for each regression are depicted in Figure 4. Equations for each regression are presented in Table 2. The diameter growth rate before the first regression line (first growth period) depends on the crown ratio. Between the first and second regression lines (second growth period) the growth rate is 16 rings per inch, between the second and third regression lines (third growth period) 32 RPI and after the third regression line (fourth growth period) 55 RPI.

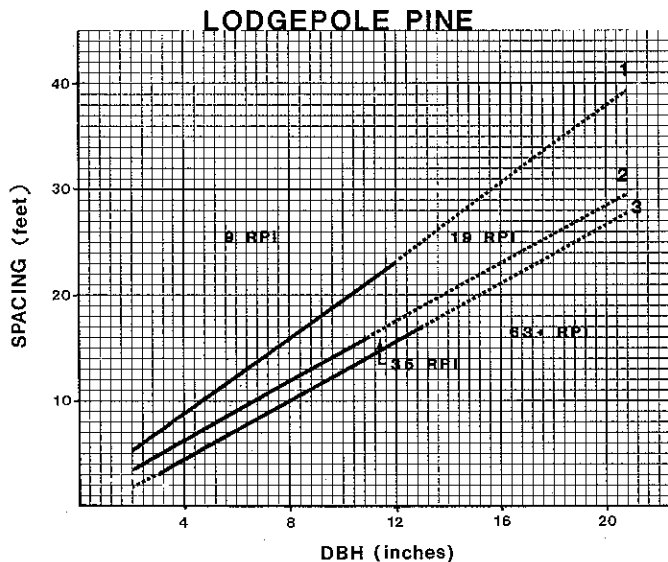


Figure 7. — Diameter growth rates (rings-per-inch) associated with tree spacing and size of lodgepole pine. Confidence intervals for each regression are depicted in Figure 4. Equations for each regression are presented in Table 2. The diameter growth rate before the first regression line is (first growth period) 9 RPI. Between the first and second regression lines (second growth period) the growth rate is 19 rings per inch, between the second and third regression lines (third growth period) 35 RPI and after the third regression line (fourth growth period) 63 RPI.

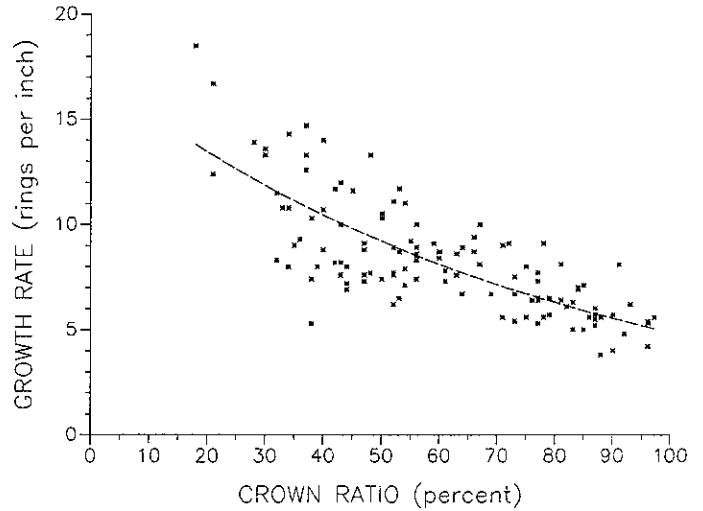


Figure 8. — Relationship of crown ratio to growth rate for ponderosa pine and Douglas-fir based on 119 observations. The curve shows that as crown decreases, tree diameter growth slows. The r^2 value for this relationship is 0.59.

Each of the nine regression equations in Table 2 are graphed according to species in Figures 5, 6, and 7. The lines depict the diameter where trees at any given spacing will reduce their growth rate to that of the next lower level. The solid lines indicate the range of the data. Growth rates are indicated above each line for that growth period. The growth rate for the first growth period of Douglas-fir and ponderosa pine (Figures 5 and 6) has been refined more than for the lodgepole pine. Here, the growth rate in the first growth period is related to crown ratio because a tree's ability to attain the maximum diameter growth rate depends on the size of its crown and its ability to carry on photosynthesis.

The relationship between crown ratio and growth rate of ponderosa pine and Douglas-fir is shown in Figure 8. At first a regression was done for both species, but the curves were so similar that the data were combined to form one curve. The purpose of this curve is to predict the growth rate of trees after thinning because the potential of a tree with a small crown, is not the same as one with a full crown. Experience on the Salmon National Forest has shown that when crown ratios are below 30% there is little response to thinning.

The primary use of this model is to predict the future diameter growth of both thinned and unthinned stands for improved forest management. As an example, suppose we precommercial thin a Douglas-fir stand to a 14 foot spacing leaving trees with an average crown ratio of 60% and a 2 inch dbh. We will then grow the stand for 140 years. The crown ratio curve (Figure 8), shows that at 60% the stand will grow at 8 RPI after thinning. This means that the stand will grow without competition (1st Growth Period) to about 7 inches dbh in the next 20 years (Figure 5). In the next 26 years the stand will grow from 7-10.3 inches dbh at a rate of 16 RPI (2nd Growth Period). The stand then slows to 30 RPI (3rd Growth Period) and grows from 10.3-13.8 inches in the next 52 years. The stand then slows down to 64 RPI (4th Growth Period) and then grows for another 42 years, reaching an average dbh of 15 inches in 140 years.

However, if at the end of the 2nd growth period we decide to commercial thin to a 28-foot spacing before the growth rate drops to 30 RPI, we will have a leave stand with an approximately 10.3 inch dbh and a crown ratio of 60%. This moves us up to a new spacing line (Figure 5). These trees will grow without competition (1st Growth Period) at 8 RPI until they reach 14 1/2 inches dbh, in another 17 years. Then the trees will grow to 20 inches dbh at 16 RPI in some 44 years. We will then harvest them at 20 inches.

Clearly, with knowledge of the growth stages you can increase tree growth dramatically by preventing the trees from entering slow growth periods. In this example, in 107 years, the stand reached 20 inches dbh. By contrast, with no commercial thin, the stand would enter the slow growth periods and reach only a 15 inch dbh in 140 years.

Table 4 shows the minimum growing space needed by 10 inch trees to maintain three different rates of growth. This is compared with the equivalent stand density indices for each.

Table 4. — Minimum growing space (ft) and maximum stand density indices (SDI) required by 10 inch trees to attain different levels of diameter growth rates, Salmon National Forest.

	Maximum rate (first growth reduction point)	Intermediate rate (second growth reduction point, about 50% of maximum)	Slower rate (third growth reduction point, about 25% of maximum)
Douglas-fir			
Spacing	19.7	13.8	10.2
SDI	110	230	420
Ponderosa pine			
Spacing	18.4	13.3	10.7
SDI	130	250	380
Lodgepole pine			
Spacing	19.8	14.6	12.9
SDI	110	200	260

The regressions in Figures 5, 6, and 7 show that the growth rates of ponderosa pine and Douglas-fir are similar, but are different from the growth of lodgepole pine. The regressions also indicate that Douglas-fir and lodgepole pine need as much or more growing space as ponderosa pine to attain the maximum diameter growth rate. In fact, Douglas-fir and ponderosa pine are able to sustain about 25% of their maximum growth rate at narrower spacing than lodgepole pine.

It will take several years to collect enough data on the Salmon National Forest to test this model. Useful data from permanent growth plots are rare within this geographic area. But we were able to test the growth model against actual growth on ponderosa pine plots from three different locations in the western United States. Table 5 compares predicted growth and actual growth from 6 plots in Arizona, 12 plots in South Dakota, and 5 plots in central Oregon. The Arizona and South Dakota studies covered two 10-year periods, with a thinning at the beginning of each period. During the first 10 years, the error of predicted versus actual growth ranged from +14% to -11.4%. During the second 10 years the error dropped to a range of +3.8% to -6.8%. This reduction in error in the second decade has also been observed in field data collected on the Salmon National Forest. Thus, to predict the growth of a stand, it is important

to use the average growth of an unthinned stand or the response of a thinned stand after it has had ample time (probably 10 years) for the growth rate to stabilize. The 25-year study from central Oregon had only one initial thinning with no midterm treatments. The r² value of actual vs predicted growth was calculated to be 0.94. The average starting diameters of the plots ranged from 2-10 inches, and average spacings were 6.6-32.5 feet. There was no significant correlation between degree of error and spacing or size of tree.

Table 5. — Diameter growth on 23 ponderosa pine plots is compared to predicted growth based on crown ratio and spacing. Twenty-year growth data from northern Arizona (Ronco *et al.* 1985), and the Black Hills, South Dakota (Edminster 1988) is divided into two 10-year intervals for each plot. The central Oregon (Barrett 1982) plot measurement interval is 25 years. Percent error was calculated according to (Predicted dbh-Ending dbh)/Starting dbh. The R² value for Actual vs. Predicted dbh is 0.94. See equations in Table 3.

Study area	Spacing (ft)	Ending crown ratio (%)	Average dbh			Percent error (%)
			Initial	Ending	Predicted	
Arizona	8.0	53	4.5	6.0	5.6	-6.7
Arizona	9.2	53	6.3	7.4	7.1	-4.1
Arizona	9.6	54	5.3	7.1	6.6	-7.0
Arizona	10.1	56	5.0	7.0	6.2	-11.4
Arizona	11.4	56	7.5	8.7	8.6	-1.1
Arizona	11.6	55	5.4	7.6	6.8	-10.5
Arizona	12.4	58	7.5	8.8	8.8	0.0
Arizona	13.2	59	5.4	7.8	7.3	-6.4
Arizona	14.6	58	8.2	9.7	9.5	-2.1
Arizona	17.7	62	8.7	10.7	10.4	-2.8
Arizona	18.5	59	5.5	8.8	8.0	-9.1
Arizona	26.7	66	9.5	12.4	12.4	0.0
South Dakota	8.4	59	3.9	5.0	5.2	4.0
South Dakota	9.3	54	5.1	6.6	6.4	-3.0
South Dakota	9.4	62	3.9	5.2	5.3	1.9
South Dakota	10.3	60	3.7	5.2	5.5	5.8
South Dakota	10.4	58	5.3	6.9	6.6	-4.3
South Dakota	10.7	50	6.8	7.4	8.0	8.1
South Dakota	11.6	55	6.6	7.6	7.8	2.6
South Dakota	11.6	50	7.5	8.6	8.6	0.0
South Dakota	11.7	58	5.4	7.3	6.8	-6.8
South Dakota	11.9	62	3.8	5.6	6.3	12.5
South Dakota	12.7	54	7.7	9.1	9.0	-1.1
South Dakota	13.2	55	6.8	8.0	8.0	0.0
South Dakota	13.9	60	5.8	7.9	7.9	0.0
South Dakota	14.3	67	3.6	5.7	6.5	14.0
South Dakota	14.6	62	6.4	7.9	8.2	3.8
South Dakota	14.6	54	8.0	9.5	9.2	-3.2
South Dakota	16.9	62	8.1	10.1	9.8	-3.0
South Dakota	17.3	66	5.9	8.5	8.8	3.5
South Dakota	18.2	58	6.6	8.2	9.1	11.0
South Dakota	20.0	64	3.7	5.7	6.2	8.8
South Dakota	21.1	60	8.4	10.5	10.9	3.8
South Dakota	24.6	69	5.9	8.8	8.8	0.0
South Dakota	26.1	63	6.6	9.0	9.1	1.1
South Dakota	32.5	68	9.2	12.2	12.1	-0.8
Central Oregon	6.6	57	1.9	4.9	4.9	0.0
Central Oregon	9.3	66	1.7	6.3	6.2	-1.6
Central Oregon	13.6	73	1.9	8.0	7.8	-2.5
Central Oregon	18.7	76	2.3	10.1	9.4	-6.9
Central Oregon	26.4	80	2.1	11.8	10.4	-11.9

MANAGEMENT APPLICATION

Our growing-space model emphasizes growing space between trees rather than average size/density indices. Thus, it allows thinning of stands to a given spacing, which is a more accurate way to reach management targets, because it considers only the land on which trees are actually growing and not the total area, including gaps in the stand. It also takes the crown ratio into consideration and whether the trees can fully respond to release (Table 3 and Figure 8).

Proper use of the spacing regressions requires that silvicultural treatments be prescribed through the remainder of the rotation to the final harvest. If spacing is to be kept relatively uniform, the size of the trees at harvest dictates the number and spacing of trees left after each thinning. Lack of consideration for final tree size and the number of intermediate cuts could result in irregular spacing and lost diameter growth, or too wide a spacing and failure to fully utilize the site.

It is beyond the scope of this paper to present the computer model that was developed from these equations but all the information needed to use the model has been included. Our next step will be to further improve the model.

With this model it is possible to maintain a consistent rate of diameter growth in even-aged stands. But as others have reminded us (Leak 1981; Ernst and Knapp 1985), we must continue to evaluate recommended stocking levels to see how close they come to satisfying our management objectives. Through this process, refinements can be made and the stocking guides can be improved.

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LITERATURE CITED

- Alexander, R. R. 1966. Site indexes for lodgepole pine, with corrections for stand density: instructions for field use. USDA Forest Service Res. Pap. RM-24. 7 pp.
- Barrett, J. W. 1982. Twenty-year growth of ponderosa pine saplings thinned to five spacings in central Oregon. USDA Forest Service Res. Pap. PNW-301. 18 pp.
- Brickell, J. E. 1968. A method for constructing site index curves from total tree age and height—its application to inland Douglas-fir. USDA Forest Service Res. Pap. INT-47. 23 pp.
- Drew T. J. and J. W. Flewelling. 1979. Stand density management: an alternative approach and its application to Douglas-fir plantations. *For. Sci.* 25:518-532.
- Edminster, C. B. 1988. [Unpublished data]. Fort Collins, CO: USDA Forest Service Rocky Mountain Research Station.
- Ernst, R. and W. H. Knapp. 1985. Forest stand density and stocking: concepts, terms, and the use of stocking guides. USDA Forest Service Gen. Tech. Rep. WO-44. 8 pp.

Gingrich, S. F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests in the central states. *For. Sci.* 13:38-53.

Husch, B., C. I. Miller and T. W. Beers. 1972. Forest mensuration. 2nd ed. John Wiley & Sons, New York. 410 pp.

Leak, W. B. 1981. Do stocking guides in the Eastern United States relate to stand growth? *J. For.* 79:661-664.

Meyer, W. H. 1938. Yield of even-aged stands of ponderosa pine. USDA Forest Service Tech. Bull. 630. 59 pp.

Reinke, L. H. 1933. Perfecting a stand-density index for even-aged forests. *J. Agri. Res.* 46:627-638.

Ronco, F., Jr., C. B. Edminster and D. B. Trujillo. 1985. Growth of ponderosa pine thinned to different stocking levels in northern Arizona. USDA Forest Service Res. Pap. RM-262. 15 pp.

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Note: The methods and theory of this paper are presented on a video tape available from U.S.D.A. Forest Service, Intermountain Region, Federal Building, 324 25th St., Ogden, UT 84401.

Factors Involved In Regenerating Interior Douglas-Fir in Dry Sites:

Natural regeneration of Douglas-fir on the drier sites in the northwest has been very unsuccessful in the past. However, natural regeneration of Douglas-fir has been achieved on the Salmon National Forest. The six key elements for successful regeneration are shade, habitat type, competition, seed sources, slash, and scarification. A video tape which illustrates these concepts is available from Ron Hamilton or Jack Amundson, U.S.D.A. Forest Service, Intermountain Region, Federal Building, 324 25th St., Ogden, UT 84401. Ph. (801) 586-5525; DG:R04A