Steven D. Tesch
Research Specialist[1]
and
Hans R. Zuuring
Station Biometrician
School of Forestry
University of Montana
Missoula, Montana 59812

Predicting Young Ponderosa Pine Growth in the Blackfoot River Drainage, Montana[2]

Abstract

The length of time required for dominant, naturally regenerated ponderosa pine (*Pinus ponderosa* Laws.) to reach diameters at breast height (b.h.) from 0.0 centimeters (cm) to 12.7 cm (5.0 inches (in.)) was predicted as a function of site index and initial spacing. Neither independent variable explained much of the variation in the time required to reach the smaller diameters, particularly the time to reach breast height. The time required to obtain a diameter at breast height ranges from four to six years for all site indexes from 10.5 meters (m) (34.4 feet (ft)) to 22.5 m (73.8 ft.) (base age 50 years). Site index becomes a more important independent variable (higher correlation with time) as d.b.h. increases, but initial spacing does not substantially affect the diameter growth rate of trees until they are nearly 12.7 cm (5.0 in) d.b.h., within the range of initial spacings included in this study. When the data were stratified by habitat type and soil mapping unit, the number of years required to reach breast height and 5.8 cm (2.0 in) b.h. was not substantially different between the strata.

Introduction

As greater emphasis is placed on the management of second-growth forests in the Northern Rocky Mountains, foresters require additional information on stand growth and development under more intensive management regimes. For trees less than 20 years old, it is particularly difficult to extrapolate existing data from naturally developed fully stocked or overstocked stands to stands which result from early stocking control. Knowledge of young stand growth and development becomes particularly important as rotations are shortened and investments in cultural treatments are considered.

Under plantation conditions the processes of competition, suppression, and mortailty may be different from stands fully stocked at establishment (Feduccia *et al.* 1979, Oliver and Powers 1978, Tesch 1980). These differences in stand development pattern ultimately affect the characteristics of the stand available for harvest.

This study attempts to quantify the length of time for naturally regenerated, dominant ponderosa pine (*Pinus ponderosa* Laws.) trees, ranging in initial spacing from 2 x 2 m (6.5 x 6.5 ft.) to open-growth (not in competition with other trees), to reach 12.7 cm (5.0 in.) b.h.

Six linear regression equations were developed to predict the time necessary to

---

[1] Current address: Forestry Intensified Research Program, Department of Forest Science, Oregon State University, 1301 Maple Grove Drive, Medford, Oregon 97501.

[2] Funding for this project was provided by Champion Timberlands, Milltown, Montana 59851.

reach breast height, 2.54 cm (1.0 in.), 5.08 cm (2.0 in.), 7.62 cm (3.0 in.), 10.16 cm (4.0 in.), and 12.7 cm (5.0 in.) b.h., as a function of site index and initial spacing. Data were also stratified to quantify the number of years to reach breast height and to 5.08 cm (2.0 in.) b.h. for three habitat types (Pfister *et al.* 1977) and three soil mapping units (USDA 1972).

Methods

Individual tree data collected by Tesch (1980) were used to determine the time required to reach various diameters at breast height. Sample trees were dominant, phenotypically superior trees. All sample trees were located in the Blackfoot River Drainage. To represent a broad range of stand and site conditions, four factors were identified: initial spacing class (2-2.9 m, 3-3.9 m, 4-4.9 m); 10-year age class (10-80 years); habitat type (3 levels) and soil mapping unit (3 levels).[3] These factors led to the formation of 189 (3 x 7 x 3 x 3) cells. A form of list sampling was employed until approximately three trees per cell were observed.

Age to respective diameter was determined by computing the difference between the age of the tree at ground level and the age of the tree at an inside bark equivalent to the desired diameter at breast height when an estimate of double bark thickness was added. Radial growth rates were obtained by averaging the measurements from two increment cores taken at breast height and bored at right angles to one another.

Using this technique to calculate the age to the desired diameter, young stand growth can be correlated with a site index measurement obtained on mature trees. This site index measurement should better represent the long-term productive capacity (in terms of height growth) of the site than one obtained from very young trees. Site index was determined by the use of local site curves developed by Tesch *et al.* (1980) (base age equals 50 years). To avoid problems with the estimation of site index for very young trees, Tesch's data were sorted to include only sample trees greater than 20 years old. The initial spacing of these older trees, measured in unmanaged stands, was estimated by a method developed by Tesch (1980).

Step-wise multiple linear regression procedures were used to develop equations predicting age to desired diameter at breast height as a function of site index and initial spacing. For model building purposes, data were screened to include trees which ranged in site index from 10.5 m (34.4 ft.) to 22.5 m (73.8 ft.) and estimated initial spacing from 1.5 x 1.5 m (4.9 x 4.9 ft.) to 5.5 x 5.5 m (18 x 18 ft.). Based on plots of the data, models were postulated as follows:

Age = f (site index, initial spacing, initial spacing x site index)

Age = f (1/site index, 1/initial spacing, 1/site index x 1/initial spacing)

Analysis of residuals was used to assess the final equations.

The data were sorted into 3 m (9.8 ft.) site index classes, using 12 m (39.4 ft.), 15 m (49.2 ft.), 18 m (59.0 ft.), and 21 m (68.9 ft.) as midpoints of the intervals. For each site index class the mode, range, mean, and standard deviation of the time required to achieve various diameters at breast height were calculated. Since ages are discrete interval data, the mode and range were chosen for descriptive purposes as appropriate measures of central tendency and dispersion, respectively. The mode is

---

[3] Habitat types and soil mapping units were selected to represent a range of potential ponderosa pine productivity classes (low, medium, high).

that datum value which occurs with the highest frequency. Arithmetic means and standard deviations were used to conduct parametric tests of significance between classes, as opposed to equivalent nonparametric tests. This switch in test procedures is one of convenience and does not influence the outcomes of various tests of hypotheses (Gaito 1972).

The mode, range, mean, and standard deviation associated with age to b.h. and to 5.08 cm (2.0 in.) b.h. were computed for each habitat type (h.t.) and soil mapping unit (SMU). The three habitat types were all in the *Pseudotsuga menziesii* series, including *Symphoricarpos albus* h.t., *Agropyron spicatum* phase (PSME/SYAL AGSP); *Symphoricarpos albus* h.t., *Calamagrostis rubescens* phase (PSME/SYAL CARU); and *Vaccinium caespitosum* h.t. (PSME/VACA). The three soil mapping units were Shooflin, Winkler, and Bignell.

Results and Discussion

Equations predicting the time required to reach various diameters at breast height are presented in Table 1. These equations represent the "best" models obtainable by stepwise linear regression procedures when fitting the two postulated model forms to the data. Final equations were selected on the basis of high R^2 values, low standard deviation about regression, and analysis of residuals. Although these may be the "best" models, because all included variables are significant, it is clear that several equations do not have "good" statistics.

The correlation between site index and age to breast height is poor. Perhaps not surprisingly, it appears that on these relatively modest productivity sites in western Montana, factors other than the long-term inherent productive potential of the site strongly influence the time it takes a dominant tree to reach breast height. For example,

TABLE 1. Equations and associated statistics for predicting number of years required to reach selected diameters at breast height.

0.0 cm b.h. (0.0 in.)	$Y = 7.2244 - 0.1178\ (\text{Site})$	$R^2 = .035$	% S.D.[a] = 35.1	n = 408
2.54 cm b.h. (1.0 in.)	$Y = 4.6830 + 79.5635\ (1/\text{Site}) - 48.2363\ (1/\text{Site} \times 1/\text{Ispa})$	$R^2 = .12$	% S.D. = 21.7	n = 408
5.08 cm b.h. (2.0 in.)	$Y = 5.4272 + 116.5166\ (1/\text{Site}) - 49.5958\ (1/\text{Site} \times 1/\text{Ispa})$	$R^2 = .22$	% S.D. = 17.5	n = 408
7.62 cm b.h. (3.0 in.)	$Y = 4.8039 + 165.7065\ (1/\text{Site})$	$R^2 = .36$	% S.D. = 16.4	n = 408
10.16 cm b.h. (4.0 in.)	$Y = 3.8620 + 224.3588\ (1/\text{Site}) + 57.3841\ (1/\text{Site} \times 1/\text{Ispa})$	$R^2 = .43$	% S.D. = 17.2	n = 407
12.7 cm b.h. (5.0 in.)	$Y = 6.5934 + 214.2031\ (1/\text{Site}) - 24.2016\ (1/\text{Ispa}) + 584.2776\ (1/\text{Site} \times 1/\text{Ispa})$	$R^2 = .52$	% S.D. = 18.6	n = 407

N

where Site = site index (m)
Ispa = initial spacing (m)

[a] Percentage S.D. = standard deviation about regression as percent of mean response.

on those sites where grasses and/or low shrubs coexist with seedlings, the competition for available soil moisture is intense.

As trees get older and thus larger in d.b.h., site index becomes an increasingly important variable for predicting the time to reach a given diameter at breast height. Probably as trees get larger, they are less likely to be strongly influenced by microsite factors that may mask the average long-term site potential.

The R^2 values associated with the equations increase as diameter increases, indicating that more variation in the age to that diameter is explained by the independent variables. Site index is the most significant variable in all equations. Initial spacing alone does not significantly influence diameter growth until age to 12.7 cm (5.0 in.) b.h. is predicted. It should be emphasized that the equations represent plantation-like initial spacing.

The data were originally stratified by site index classes and initial spacing classes to visualize patterns that would make model building more efficient. However, when it became clear that statistically desirable prediction equations were not always possible using the selected independent variables, the number of years required to reach the desired diameter was determind for each of four site index classes (Table 2). Using

TABLE 2. Modal number of years required to reach various diameters at breast height for 3 m (9.8 ft.) site index classes.

	Model number of years	Range	n
Years to breast height			
Site Index 12 m (39.4 ft.)	5	9	33
15 m (49.2 ft.)	4	13	139
18 m (59.0 ft.)	5	8	142
21 m (68.9 ft.)	6	8	65
Years to 2.54 cm b.h. (1.0 in.)			
Site Index 12 m	10	10	33
15 m	9*	12	139
18 m	9*	9	142
21 m	9	7	65
Years to 5.08 cm b.h. (2.0 in.)			
Site Index 12 m	14	11	33
15 m	11*	11	139
18 m	11*	10	142
21 m	9	8	65
Years to 7.62 cm b.h. (3.0 in.)			
Site Index 12 m	17*	15	33
15 m	15*	14	139
18 m	14*	11	142
21 m	11	9	65
Years to 10.16 cm b.h. (4.0 in.)			
Site Index 12 m	22*	27	33
15 m	19*	18	139
18 m	17*	13	141
21 m	16	14	65
Years to 12.7 cm b.h. (5.0 in.)			
Site Index 12 m	28*	37	32
15 m	23*	25	137
18 m	21*	15	135
21 m	19	19	64

*Significant difference between mean number of years to reach a specific d.b.h. at site index group i and i + 3, where i = 12, 15, 18. Tests of significance were performed using Cochran's Approximation for two sample t-tests with unequal subclass numbers (Snedecor and Cochran 1967).

parametric test procedures, statistically significant differences (at the 5 percent level) in mean number of years were found between site index classes at larger diameters. At small diameters, practical differences are only one or two growing seasons.

The uniform period required for dominant trees to reach breast height is interesting. This uniformity suggests that on poor sites a very favorable microsite can support

TABLE 3. Modal number of years required to reach b.h. and 5.08 cm (2.0 in.) b.h. for selected habitat types and soil mapping units.

	Model number of years	Range	n
Years to breast height			
PSME/SYAL AGSP h.t.	6	13	117
PSME/SYAL CARU h.t.	6	11	116
PSME/VACA h.t.	4	8	125
Bignell SMU	5	13	162
Shooflin SMU	6	11	136
Winkler SMU	5	8	105
Years to 5.08 cm (2.0 in.) b.h.			
PSME/SYAL AGSP h.t.	13	13	117
PSME/SYAL CARU h.t.	11	12	116
PSME/VACA h.t.	11	12	125
Bignell SMU	12	13	162
Winkler SMU	11	12	105
Shooflin SMU	11	13	136

TABLE 4. T-tests for significant differences between the arithmetic mean length of time required to reach breast height and 5.08 cm (2.0 in.) b.h. for sampled habitat types and soil mapping units.

Diameter class	t'	Growth rate implication[1]
Years to breast height		
PSME/SYAL AGSP h.t. (PSA) vs. PSME/SYAL CARU h.t. (PSC)	1.79	
PSME/SYAL AGSP h.t. vs. PSME/VACA h.t. (PV)	3.68*	PSA>PV[2]
PSME/SYAL CARU vs. PSME/VACA	1.70	
Bignell SMU (B) vs. Winkler SMU (W)	1.86	
Shooflin SMU (S) vs. Bignell SMU	0.00	
Shooflin SMU (S) vs. Winkler SMU	1.80	
Years to 5.08 cm (2.0 in.) b.h.		
PSME/SYAL AGSP h.t. vs. PSME/SYAL CARU h.t.	3.33*	PSA>PSC
PSME/SYAL AGSP h.t. vs. PSME/VACA h.t.	3.40*	PSA>PV
PSME/SYAL CARU vs. PSME/VACA	2.02*	PSC>PV
Bignell SMU vs. Winkler SMU	2.60*	B>W
Bignell SMU vs. Shooflin SMU	1.27	
Winkler SMU vs. Shooflin SMU	1.31	

*Significant differences at the 5 percent level of t' (Snedecor and Cochran 1967).

[1] Growth rate implication refers to significant differences in arithmetic mean number of years required to reach the specific diameter.

[2] > Implies greater time required.

height growth at a rate essentially equal to that on better sites. On better sites, however, where overall environmental conditions may be more favorable, location within a more favorable microsite does not increase early height growth.

The number of years required to reach b.h. and 5.08 cm (2.0 in.) b.h. on the three habitat types and three soil mapping units is presented in Table 3. Once again, while statistically significant differences do occur between strata using the arithmetic mean number of years (Table 4), particularly for the 5.08 cm (2.0 in.) b.h. diameter class, practical differences are small.

Conclusions

It appears difficult to predict the height growth of young ponderosa pine using variables that are related to the long-term productive height growth potential of the site. These results document the variability in height growth rate of young vigorous trees that exhibited no previous suppression of radial growth at ground level. This variability must be due to variables other than site index. Stratification by habitat type, which theoretically provides a measure of long-term average understory microclimate, still does not appear to account for the short-term variation in such factors as temperature or moisture availability. To quantify the height growth of young ponderosa pine precisely, independent variables must be identified that can account for the short-term variability in growing conditions. Such variables might include growing season precipitation (amount and timing) and temperature (average and extremes); understory vegetation composition, phenology, structure, and density; and animal browsing.

Literature Cited

Feduccia, D. P., T. R. Dell, W. F. Mann, Jr., T. E. Campbell, and B. H. Polmer. 1979. Yields of Unthinned Loblolly Pine Plantations on Cutover Sites in the West Gulf Region. USDA For. Serv. Res. Pap. SO-148.

Gaito, J. 1972. Scale classification and statistics, *in* Statistical Issues: A Reader for the Behavioral Sciences, R. E. Kirk (ed.). Brooks Cole Pub. Co., Monterey, Calif.

Oliver, W. W., and R. F. Powers. 1978. Growth Models for Ponderosa Pine: 1. Yield of Unthinned Plantations in Northern California. USDA For. Serv. Res. Pap. PSW-133.

Pfister, R. D., B. L. Kovalchik, S. F. Arno, and R. C. Presby. 1977. Forest Habitat Types of Montana. USDA For. Serv. Gen. Tech. Report INT-34.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical Methods. 6th Edn. Iowa State Univ. Press, Ames, Iowa.

Tesch, S. D. 1980. Aboveground Biomass Yields for Short Rotation Ponderosa Pine Stands in Western Montana. Univ. of Montana, Missoula, Ph.D. Thesis (Univ. Microfilms, 81-12785).

———, H. R. Zuuring, and J. L. Faurot. 1980. Pondersa Pine Site Curves for the Blackfoot River. Drainage, Montana. Mont. For. and Cons. Exp. Sta. Res. Note NO. 15.

USDA. 1972. Soil Survey, Lower Blackfoot Area, Missoula County, Montana. Preliminary report. Conservation District Office, Missoula, Mont.

Received May 5, 1981
Accepted for publication December 3, 1982