# Stand Density Guides for Predicting Growth of Forest Trees of Southwest Idaho

**Douglas D. Basford[1], John Sloan[2], and Joy Roberts[3]**

**Abstract**—This paper presents a method for estimating stand growth from stand density and average diameter in stands of pure and mixed species in Southwest Idaho. The methods are adapted from a model developed for Douglas-fir, ponderosa pine, and lodgepole pine on the Salmon National Forest. Growth data were derived from ponderosa pine increment cores taken from sample plots on the Boise and Payette National Forests. The model was tested against growth plots and permanent inventory plots located on the Boise and Payette National Forests. Model results closely fitted observed dbh's on these managed and unmanaged stands. These stands were summarized by group with average errors ranging from 0.8 to 2.9 percent ($r^2$ = 0.90 to 0.96).

## Introduction

Stand density is a critical element in managing forests of the Western United States. Although managing stand density is commonly associated with timber production, it also affects wildlife habitat, water yield, and other forest resources. To manage forests, resource managers need accurate tools to predict how stand density affects future growth, which in turn affects various forest uses and values. The Relative Stand Density Index (Drew and Flewelling 1979) and Reineke's Stand Density Index (Gingrich 1967; Reineke 1933) provide useful formats in some situations.

Basford and others (1991) discussed the stand density considerations in forest treatments and the procedure of establishing and measuring permanent growth plots over time. Subjective decision processes based only on experience or related published data, are less time consuming but can lead to less accurate results. Consequently, inappropriate growing space applied during thinning treatments, or a delay in thinning, has caused reduced canopies and slower stand growth than expected.

To address these questions, a 1991 study on the Salmon NF developed stocking guides for Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.), and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) (Basford and others 1991). The model developed for ponderosa pine is called the Salmon-Challis ponderosa pine model (SCPP), and using this model helped foresters on the Salmon NF make better predictions about growth expected after thinning.

In 1999, personnel from the timber staff on the Boise and Payette National Forests (NFs) requested that a study be undertaken to determine stand density recommendations for ponderosa pine, because current recommendations were not working. The majority of all 30 to 50 year old plantations on the Boise and Payette NFs had been thinned at least once in the last 20 to 30 years. Most did

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not respond to thinning treatments as desired due to inadequate spacing to allow stand release.

As a result of this concern, staffers adopted the approach that had worked to build the SCPP model. That result, the Boise-Payette ponderosa pine model (BPPP), predicts the future diameter growth and density of both thinned and unthinned stands in southwest Idaho. The model allows managers to closely replicate stand growth rates using an automated process that otherwise would be acquired only through repetitive permanent sample plots.

Development of the BPPP stand growth models for the southwest Idaho forests included the use of computer program (BKTHIN) that allows for data input, model processing and tabular output. The program is easy to use and does not require large amounts of complex data. The growth models are based on measurements from individual trees and their observed growth patterns. To validate the accuracy of the models, tests were run using stand data from permanent growth and inventory plots. The predicted growth was compared to actual measured growth. This computer program, BKTHIN, is an important and efficient tool to help manage forest stands to meet identified objectives.

# Methods, Results, and Discussion

The following discussion is organized to first summarize data collection of sample, released, and "free-to-grow" trees, followed by a description of the development of mathematical models (BPPP and SCPP, within the BKTHIN computer program), and ending with a summary of model validation.

## *Data Collection*

The growth equations for the Boise and Payette NFs were derived by analyzing increment cores, rather than by measuring permanent sample plots over time. Increment cores were taken from ponderosa pine trees in plots of different density levels on the two National Forests. A total of 133 plots were selected, representing an average diameter range of 2 inches up to 22 inches. Each plot contained a sample tree, surrounded by other trees of the same species, uniform in size and spacing, so that each sample tree experienced consistent competition on all four sides (fig. 1). All sample plots were free from mortality and from insects and disease. It was assumed that any reductions in growth rates would be related to density.

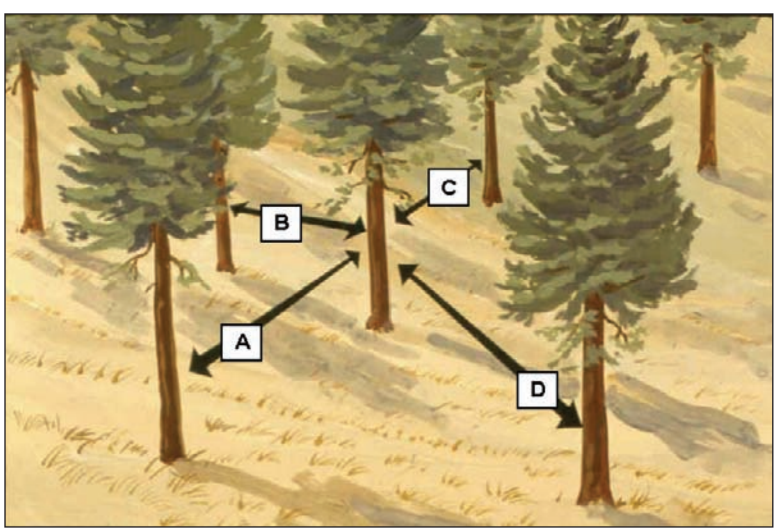


**Figure 1**—Distribution of sample tree to adjacent trees (A through D)

Sample tree selection and data collection followed procedures outlined in Basford and others (1991). Sample plots of uniform condition were located. Sample trees were selected from stands with a relatively narrow range of tree diameters and spacing, with at least four adjacent competing trees (fig. 1). Sample trees were selected so that the diameter differences between the sample tree and adjacent competing trees did not exceed one third of the diameter of the sample tree (for example, if the sample tree diameter at breast height was 9 inches, the diameter of the adjacent trees was between 6 and 12 inches.). Also, the distance between the sample tree and the four adjacent trees could not differ by more than 25 percent.

Increment cores were taken from the uphill and downhill side of each sample tree. Measurements on each increment core to record radial distance inside bark to each identified growth period were taken and then averaged (fig. 2). Diameter outside bark was calculated using the equation described by Husch and others (1972).

The average number of rings per inch (rpi) for each growth period was calculated by dividing the number of rings by the length of the core within that period, and then averaging the measurements from the uphill and downhill cores.

On each sample plot, site and tree data were collected. Data from sample plots of similar site quality (habitat type) were grouped, and the distances between the boles of the sample tree and adjacent trees were averaged. A linear regression line for the transition points between each growth period was drawn. For all regressions, graphs of residuals versus predicted values were examined, and standard deviations about the regressions were calculated as measures of reliability.

**"Free-to-grow" trees**—To establish potential diameter growth rates for trees without competition, large open-grown ponderosa pine trees were sampled. These were called "free-to-grow" trees. A total of 17 of these trees were sampled, 11 on the Idaho City Ranger District, Boise NF, and 6 on the Council Ranger District, Payette NF. Increment cores and bark thickness were taken from each sample tree, and rpi was calculated using the same tree sampling procedures as identified earlier.

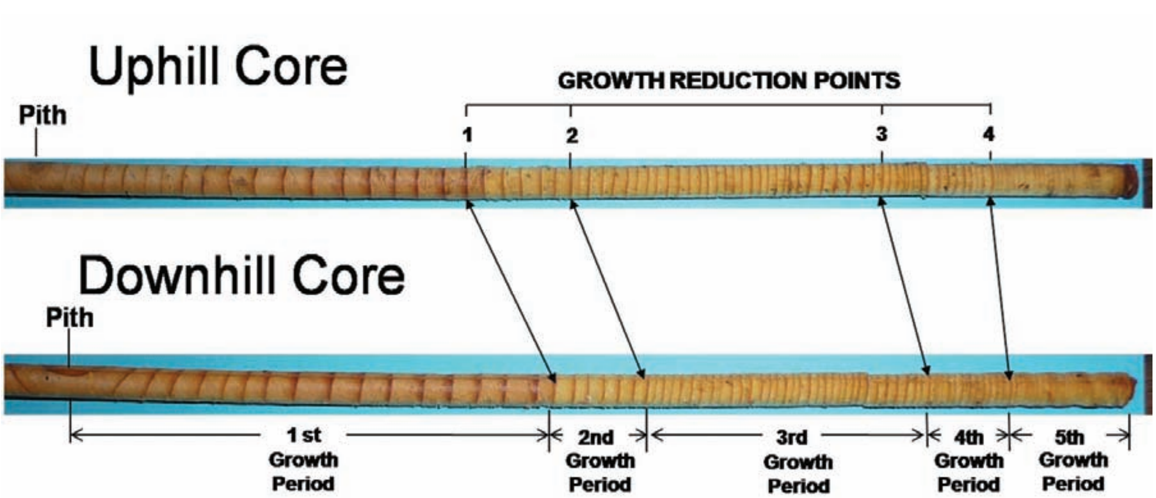


**Figure 2**—These cores are from a sample tree to illustrate growth rates, periods of uniform growth, and points at which growth reduction occurs. An additional 6$^{th}$ growth period was identified on other core samples. Rings per inch (RPI) are computed for each growth period.

**Live crown ratio of released trees**—Released trees are those that have been under competition at some previous point but, that at the time of measurement, were not competing with other trees. These trees had a smaller live crown ratio than open-grown trees of similar diameter, due to competition before thinning. Live crown ratios were measured and growth rates calculated in order to determine potential growth rates when a stand had been thinned and released from competition (table 1). This aspect is important to the model because it will determine what the maximum growth rate will be after thinning.

## *Analysis of Data*

**Sample tree**—The cores from trees that met the strict sample criteria all showed identifiable transitions, usually over a period of two to three rings where growth slowed. After each identifiable growth reduction point (transition), the rings in the core will again grow at a fairly constant, although slower, rate. The cores in figure 2 show these growth reduction points and growth periods. If the strict sampling criteria were not met, these key transition points between growth periods, which are very gradual, and could be misidentified. The analysis also shows that the timing and diameter at these reduction points can be predicted (fig. 3).

Each of these five growth reduction points was grouped. From these groups, a linear regression was computed between average tree spacing (Y) and diameter (X) of the sample trees. The resulting equations represent lines at which the growth reduction is expected to take place as a stand grows, at any given density and average diameter (table 2).

**Table 1**—Crown ratio measurements. The spacing and average diameters were grouped into crown ratio classes and a regression calculated. The independent variable, X, is the tree diameter (inches). The dependent variable, Y, is tree spacing (ft).

| Species | Crown ratio | Sample size | Crown competition equations | $r^2$ | Predicted rings/inch after release | 10 year diameter growth after release |
|---|---|---|---|---|---|---|
| | *(percent)* | | | | | *(inches)* |
| Douglas-fir | 60 - 70 | 17 | Y = 1.86 + 1.15X | 0.85 | 8.4 | 2.4 |
| (Salmon-Challis N.F.) | 50 - 59 | 20 | Y = 1.42 + 0.98X | 0.79 | 8.8 | 2.3 |
| | 40 - 49 | 26 | Y = 0.89 + 0.94X | 0.68 | 10.4 | 1.9 |
| | 30 - 39 | 10 | Y = 0.88 + 0.88X | 0.81 | 12.8 | 1.6 |
| | < 30 | | — | — | 17.2 | 1.2 |
| Ponderosa pine | 60 - 70 | 7 | Y = 0.46 + 1.14X | 0.90 | 8.3 | 2.4 |
| (Salmon-Challis N.F.) | 50 - 59 | 12 | Y = 0.45 + 1.04X | 0.92 | 9.4 | 2.1 |
| | 40 - 49 | 18 | Y = –0.22 + 1.02X | 0.78 | 10.8 | 1.9 |
| | 30 - 39 | 11 | Y = –1.29 + 1.04X | 0.87 | 13.0 | 1.5 |
| Lodgepole pine | 50 - 70 | 38 | Y = –0.39 + 1.32X | 0.52 | No Data | No Data |
| (Salmon-Challis N.F.) | 30 - 40 | 15 | Y = –1.26 + 1.26X | 0.65 | No Data | No Data |
| Ponderosa pine | 60 - 80 | 55 | Y = –0.50 + 1.35X | 0.84 | 5.4 | 3.7 |
| (Boise-Payette N.F.'s) | 50 - 59 | 57 | Y = –0.48 + 1.18X | 0.71 | 6.9 | 2.9 |
| | 40 - 49 | 24 | Y = –1.44 + 1.17X | 0.82 | 6.9 | 2.9 |
| | 30 - 39 | 11 | Y = –1.46 + 1.05X | 0.85 | 7.4 | 2.7 |
| | < 30 | | — | — | 10.7 | 1.9 |

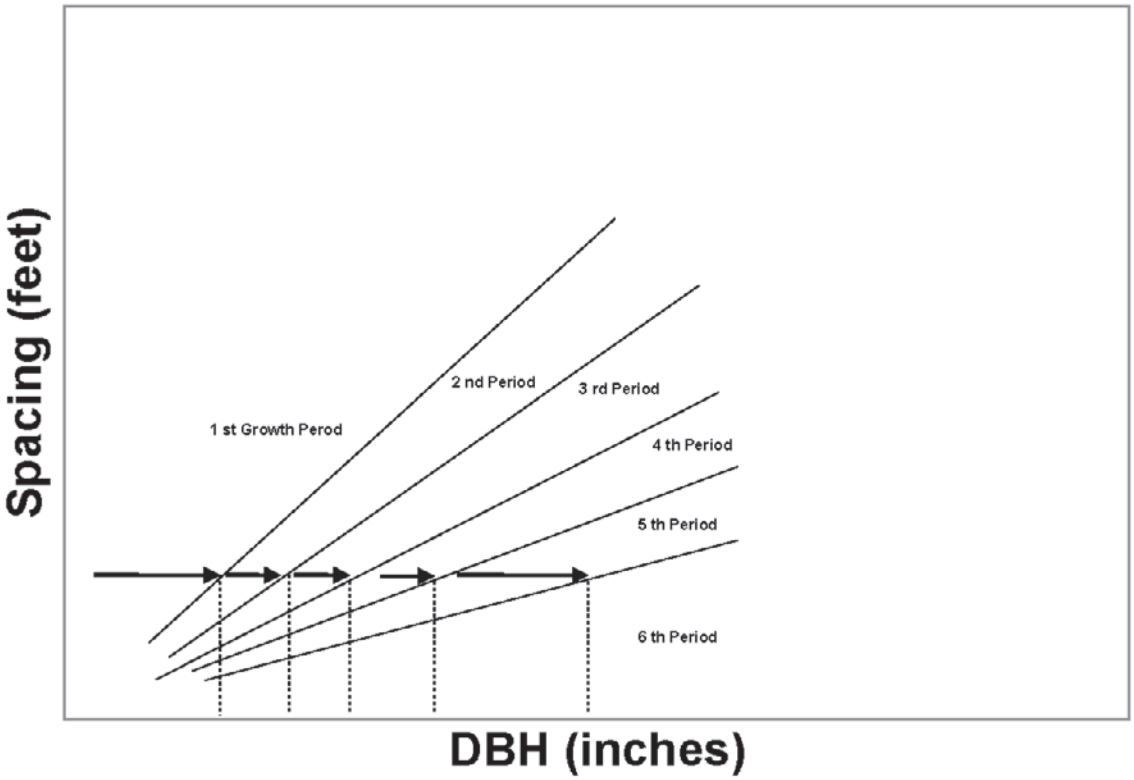


**Figure 3**—Spacing and diameter related to growth reduction lines and growth periods.

**Table 2**—Comparison of tree spacing / diameter regression equations. Regression equations represent the transitions between the maximun average growth rates. The independent variable, X, is the tree diameter. The dependent variable, Y, is tree spacing. The Boise-Payette equations are presented graphically in figure 4.

| Species | Average growth rate (rings/in) | 10 year diameter growth (inches) | Sample size | Range of data (dbh) (inches) | Equations (X = Diameter) (Y = Spacing) | $r^2$ |
|---|---|---|---|---|---|---|
| Douglas-fir | | | | | | |
| (Salmon-Challis N.F.) | 8.4 | 2.4 | 36 | 1.1-14.3 | Y = 1.11 + 1.85X | 0.91 |
| | 16.0 | 1.3 | 29 | 2.4-21.2 | Y = 1.10 + 1.25X | 0.88 |
| | 29.6 | 0.7 | 7 | 5.6-14.2 | Y = 0.08 + 1.01X | 0.92 |
| Ponderosa pine | | | | | | |
| (Salmon-Challis N.F.) | | | | | | |
| | 8.3 | 2.4 | 25 | 1.0-11.9 | Y = 2.68 + 1.58X | 0.86 |
| | 16.4 | 1.2 | 21 | 2.2-16.2 | Y = 1.09 + 1.23X | 0.91 |
| | 31.6 | 0.6 | 8 | 4.1-20.8 | Y = 0.59 + 1.02X | 0.96 |
| Lodgepole pine | | | | | | |
| (Salmon-Challis N.F.) | | | | | | |
| | 8.9 | 2.2 | 39 | 1.6-12.4 | Y = 1.63 +1.80X | 0.9 |
| | 19.4 | 1.0 | 37 | 2.2-10.6 | Y = 0.62 + 1.39X | 0.81 |
| | 35.1 | 0.6 | 22 | 2.7-12.6 | Y = –1.10 + 1.41X | 0.89 |
| Ponderosa pine | | | | | | |
| (Boise and Payette N.F.’s) | 5.4 | 3.7 | 63 | 2.3-16.4 | Y = 1.72 + 1.72X | 0.88 |
| | 9.6 | 2.1 | 30 | 4.4-22.1 | Y = 1.72 + 1.43X | 0.81 |
| | 13.4 | 1.5 | 19 | 2.5-17.5 | Y = 1.57 + 1.24X | 0.77 |
| | 23.1 | 0.9 | 14 | 3.2-19.7 | Y = 1.48 + 1.01X | 0.99 |
| | 44.3 | 0.5 | 7 | 3.6-19.7 | Y = 0.60 + 0.93X | 0.96 |

**Free-to-grow**—Data from the free-to-grow trees were used to determine the potential diameter growth rates in the absence of intertree competition as described above. Increment core analysis of the free-to-grow trees showed periods of relatively uniform diameter growth separated by points of identifiable growth reduction (table 3). Average diameter was computed at each growth reduction point and average growth rate was computed for each growth period. However, in these trees, growth reductions were due to tree physiology and occurred at larger diameters than those under competition.

The potential radial growth rates from free-to-grow trees were used to validate the average rpi for the first growth period of the sample trees. Sample trees that showed growth rates that were not within three rings of the potential rate for the site, as indicated by the free-to-grow trees, were rejected because their growth rates exceeded the identified variance. The reduced growth rates were likely due to an unidentified cause such as competition from nearby trees that had since disappeared.

**Crown ratio of released trees**—The last, and important, part of the analysis is the live crown ratio component. As stand competition increases, live crown ratios become smaller. Crown ratios and diameter growth rates were measured on trees that had been released from competition through thinning. The live crown ratios were grouped and the growth rates (rpi) within each group were averaged. It was found that when the live crown ratios are 60 percent or greater, the predicted growth rate closely reflected potential diameter growth rate (table 1). When the live crown ratio is less than 60 percent, the reduced photosynthetic base prevents the trees from reaching its predicted growth potential. When live crown ratio falls below 20 percent, little or no response is expected from a tree retained after thinning.

After calculating the predicted radial growth rate following thinning, the model compares it to the growth rate based on the crown ratio of release trees, and chooses the slower of the two. In this way, the model prediction would not allow a stand to grow faster than a reduced crown ratio would allow.

## *Computer Program Development*

The mathematical models were programmed into a framework to facilitate user input, data processing and tabular output. The program was compiled using Microsoft Visual Basic®6.0. This computer application called BKTHIN can be run on most computers using Windows operating systems. The software and a user's guide can be obtained upon request. The minimum inputs are stand density and diameter. Remaining inputs can be used to further refine the results.

## *The BPPP Model*

We compared results for the Boise-Payette model (BPPP) with three similar models from the Salmon-Challis National Forest (Salmon-Challis ponderosa pine = (SCPP), Salmon-Challis Douglas-fir = (SCDF), and Salmon-Challis lodgepole pine = (SCLP) (Basford and others 1991). The Boise-Payette model is based on more sample plots than the Salmon- Challis models, but the range of sample tree size is very close. The BPPP model generates faster growth rates than the other three, and has five growth reduction regression lines compared to three regression lines for the other models (table 2). The growth rates are slower in the Salmon-Challis models because they were developed from drier sites with 100-year site indices ranging from 60 to 80, whereas Boise and Payette NFs sites have 100-year site indices in the range of 80 to 115. These groups of growth reduction lines are limited by the size of sample trees available to sample. If larger sample

**Table 3**—Mean diameter growth rates during each growth period and the mean diameter at the growth reduction points for free-to-grow trees. The formula to convert rings/inch to diameter growth per decade = 20/rings per inch.

| | | | | | Growth reduction points | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ranger District/ Forest | Species[a] | Habitat Type | Site index mean[b] | No. of trees in sample | Rings/inch before 1st | dbh at 1st | Rings/inch between 1st and 2nd | dbh at 2nd | Rings/inch between 2nd and 3rd | dbh at 3rd | Rings/inch between 3rd and 4th |
| North Fork/SCNF[c] | PP | Psme/Caru-Pipo<br>Psme/Cage-Pipo<br>Psme/Syal-Pipo | 75 | 11 | 7.5 | 13.2 | 12.4 | 19.8 | 19.8 | 26.1 | 26.8 |
| Idaho City/BNF[de] | PP | Psme/Caru-Pipo<br>Psme/Spbe-Pipo<br>Psme/Syal-Pipo<br>Psme/Cage-Pipo<br>Psme/Phma-Pipo | 109 | 11 | 7.4 | 22.3 | 11.5 | 30.9 | 20.2 | 36.4 | 32.1 |
| Council/PNF[f] | PP | Abgr/Spbe<br>Abgr/Caru | 115 | 6 | 6.9 | 25.8 | 11.6 | 31.7 | 17.7 | 35.2 | 36.3 |
| Salmon/SCNF | DF | Psme/Feid-Feid<br>Psme/Caru-Feid | 65 | 4 | 9.2 | 12.8 | 16.3 | 21.9 | 21.2 | | |
| Leadore/SCNF | DF | Psme/Caru-Caru | 65 | 3 | 8.9 | 11.5 | 12.4 | 18.3 | 25.9 | | |
| Salmon/SCNF | DF | Psme/Caru-Caru | 75 | 4 | 7.8 | 16.4 | 10.8 | 26.6 | 17.0 | 33.2 | 29.2 |
| North Fork/SCNF | DF | Psme/Caru-Pipo | 82 | 3 | 8.1 | 20.5 | 13.7 | 28.5 | 23.9 | 30.6 | 44.6 |
| Salmon/SCNF | LPP | Psme/Caru-Caru | 68 | 6 | 7.1 | 9.5 | 11.8 | | | | |

[a] PP = ponderosa pine, DF = Douglas-fir, LPP = Lodgepole pine
[b] of 100-year base age
[c] SCNF = Salmon-Challis National Forest
[d] BNF = Boise National Forest
[e] Tree diameters on the BNF were larger than the SCNF resulting in the additional growth reduction points listed as follows: dbh at 4th = 42.2, rpi between 4th and 5th = 43.3, dbh at 5th = 46.6, rpi between 5th and 6th = 60.5, dbh at 6th = 52.4, rpi after 6th reduction = 77.5
[f] PNF = Payette National Forest

trees could have been found that met the sample criteria, more growth reduction equations would have been developed. The $r^2$ values for the BPPP model reduction equations for all models show that the data points (Y=spacing and X=dbh) form acceptable linear relationships.

The growth reduction equations in table 2 for ponderosa pine on the Boise-Payette NFs are graphed in figure 4. This figure shows the simplified results of the BPPP model. The solid lines represent the range of data. Dotted lines indicate where growth rates have been extrapolated. Using the average spacing and the average diameter, the growth of a ponderosa pine stand can be predicted using the graph. For instance, a stand grown for 80 years, starting with a mean diameter of 4 inches and a spacing of 16 feet, will grow at a rate of 5.4 rpi (3.7 inches/decade), reaching a mean diameter of 8.3 inches in the first growth period. In the second growth period, growth will slow to 9.6 rpi (2.08 inches/decade), and the stand will reach a mean diameter of 9.9 inches. Growth will then slow to 13.4 rpi (1.49 inches/decade) in the third growth period, and the stand will attain a mean diameter of 11.5 inches. Growth then slows to 23.1 rpi (0.87 inches/decade) in the fourth growth period with a mean diameter of 14.4 inches. Finally, in the fifth growth period the rpi slows to 44.3 rpi (0.45 inches/decade), reaching a mean diameter of 16.8 inches within the 80 years allowed by the model. The stand will have grown from 4 inches to 16.8 inches in an 80 year period without thinning. To predict the results of a thinning to increase the growth rate, simply move up the spacing axis to the new spacing and continue from there.

The other component of the BPPP model is live crown ratio. The live crown ratio observations were averaged and show that as crown decreases, tree diameter growth slows. This average is used in BPPP to determine the predicted growth of

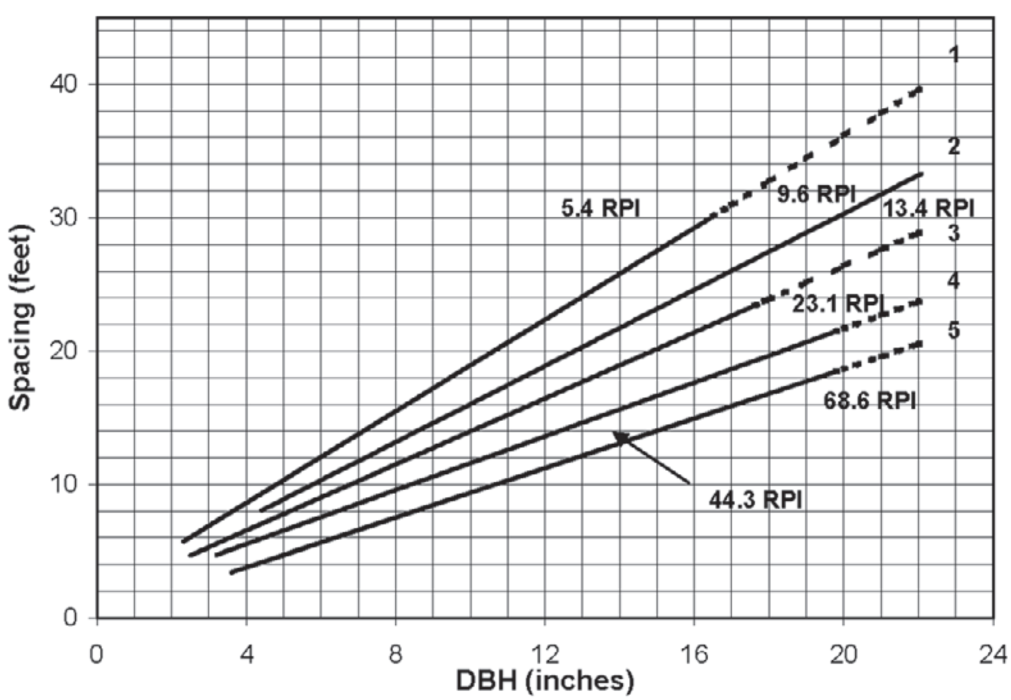


**Figure 4**—Ponderosa pine diameter growth rates (rings-per-inch, rpi) associated with spacing and tree size in the Boise-Payette National Forests. Equations for each regression line are presented in table 2. The solid lines represent the range of data and the dotted lines where growth rates have been extrapolated. The diameter growth before the first regression line (first growth period) is 5.4 rpi, second growth period 9.6 rpi, third growth period 13.4 rpi, fourth growth period 23.1 rpi, fifth growth period 44.3 rpi, and the sixth growth period 68.6 rpi.

a stand after its release from intertree competition. For example, if the live crown ratio is above 60 percent, then the predicted growth rate in the first growth period will be 5.4 rpi. Below 60 percent the growth rate slows. Below 30 percent live crown ratio, the expected growth rate should be only 10.7 rpi (table 1).

## *BKTHIN Output*

Table 4 presents an example of the BKTHIN program output. All of the settings that have been entered are displayed in the heading of the output. In this example, using the Boise/Payette model, the beginning stand diameter was 4.2 inches at

**Table 4**—Example of an output from the Boise-Payette BPPP model. YR = Year; AGE = average stand age; DIAMETER = average diameter at breast height (inches); D-Gr RPI = diameter growth in rings per inch; T/A = trees per acre; HT = average height (ft); CU-FT = stand volume in cubic feet per acre; MAI = mean annual increment in cubic feet per acre; MBF = stand volume in 1000 board feet per acre; MAIBF = mean annual increment in board feet per acre; BA/A = basal area per acre; R-SDI = Reinke's stand density index; MCA= maximum crown area, CCF = crown competition factor; CR-% = crown ratio percent/10; CW = crown width in feet; CSEP = crown separation distance in feet; WPB = western pine beetle index from low (0), to high (11).

7/9/2005 Rev 4.0.9 8/24/2004 BOISE/PAYETTE NF BASFORD-KEENE PROGRAM
INITIAL STAND CONDITIONS
Stand Description: PP/DF Site Stand Table
Productivity Class: Medium
Height Relation: DBH/HT
Average Stand Diameter: 4.2
Optimum Diameter Growth: 5.4
Initial Spacing: 9.0 X 9.0 ft.
Stockability %: 100
Stand Age: 30
Years Projected: 27

Mortality Factor for 6 Growth Periods: .05, 0.1, 0.3, 0.3, 0.5, 0.5

THINNING INFORMATION
Distribution: User Specified
Thinning Diameters: 4.2, 12.1, 0.0, 0.0, 0.0 in.
After Thin Spacing: 18.0, 24.0, 0.0 ft
Minimum Cut MBF: 0.0

| YR | AGE | DBH | D-G RPI | T/A | HT | CU-FT | MAI | MBF | MAIBF | BA/A | R-SDI | MCA | CR-% | CW | CSEP | WPB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 30 | 4.2 | 5.4 | 538 | 24 | 0 | 0.0 | 0.0 | 0 | 52 | 134 | 51 | 7-9 | 7 | 1.9 | 0.0 |
| **COMM THIN REMOVAL** | | | | 403 | | 0 | | 0.0 | Thinned to: 18.0 X 18.0 Ft. | | | | | | | |
| **1** | 31 | 4.6 | 5.4 | 134 | 26 | 0 | 0.0 | 0.0 | 0 | 16 | 39 | 14 | 7-9 | 8 | 10.5 | 1.0 |
| **2** | 32 | 5.1 | 5.4 | 134 | 28 | 0 | 0.0 | 0.0 | 0 | 19 | 45 | 16 | 7-9 | 8 | 10.1 | 1.2 |
| **3** | 33 | 5.5 | 5.4 | 134 | 30 | 0 | 0.0 | 0.0 | 0 | 22 | 51 | 18 | 7-9 | 8 | 9.7 | 1.2 |
| **4** | 34 | 5.9 | 5.4 | 134 | 32 | 0 | 0.0 | 0.0 | 0 | 26 | 58 | 20 | 7-9 | 9 | 9.2 | 1.2 |
| **5** | 35 | 6.3 | 5.4 | 134 | 34 | 0 | 0.0 | 0.0 | 0 | 29 | 64 | 23 | 7-9 | 9 | 8.8 | 1.2 |
| **6** | 36 | 6.8 | 5.4 | 134 | 35 | 0 | 0.0 | 0.0 | 0 | 33 | 71 | 25 | 7-9 | 10 | 8.4 | 1.2 |
| **7** | 37 | 7.2 | 5.4 | 134 | 37 | 301 | 13.7 | 1.3 | 244 | 38 | 79 | 27 | 7-9 | 10 | 8.0 | 1.2 |
| **8** | 38 | 7.6 | 5.4 | 134 | 39 | 392 | 17.1 | 1.3 | 233 | 42 | 86 | 30 | 7-9 | 10 | 7.6 | 1.2 |
| **9** | 39 | 8.0 | 5.4 | 134 | 41 | 494 | 20.6 | 1.3 | 224 | 47 | 94 | 32 | 7-9 | 11 | 7.1 | 1.2 |
| **10** | 40 | 8.5 | 5.4 | 134 | 43 | 606 | 24.2 | 1.3 | 215 | 52 | 102 | 35 | 7-9 | 11 | 6.7 | 1.2 |
| **11** | 41 | 8.9 | 5.4 | 134 | 44 | 728 | 28.0 | 1.3 | 206 | 58 | 111 | 38 | 7-9 | 12 | 6.3 | 1.2 |
| **12** | 42 | 9.3 | 5.4 | 134 | 46 | 861 | 31.9 | 1.3 | 199 | 63 | 119 | 41 | 7-9 | 12 | 5.9 | 1.2 |
| **13** | 43 | 9.7 | 9.6 | 133 | 48 | 1006 | 35.9 | 1.3 | 192 | 69 | 128 | 44 | 7-9 | 13 | 5.5 | 1.2 |
| **14** | 44 | 10.0 | 9.6 | 133 | 49 | 1092 | 37.6 | 1.3 | 185 | 72 | 133 | 46 | 7-9 | 13 | 5.2 | 1.2 |
| **15** | 45 | 10.2 | 9.6 | 133 | 50 | 1181 | 39.4 | 1.6 | 187 | 76 | 138 | 47 | 7-9 | 13 | 5.0 | 1.4 |
| **16** | 46 | 10.5 | 9.6 | 133 | 51 | 1274 | 41.1 | 2.1 | 199 | 79 | 143 | 49 | 7-9 | 13 | 4.8 | 1.4 |
| **17** | 47 | 10.7 | 9.6 | 133 | 52 | 1371 | 42.8 | 2.7 | 211 | 83 | 148 | 51 | 7-9 | 13 | 4.5 | 1.4 |
| **18** | 48 | 10.9 | 9.6 | 133 | 52 | 1471 | 44.6 | 3.3 | 223 | 87 | 153 | 53 | 7-9 | 14 | 4.3 | 1.4 |
| **19** | 49 | 11.2 | 9.6 | 133 | 53 | 1576 | 46.3 | 3.9 | 234 | 90 | 159 | 55 | 7-9 | 14 | 4.1 | 4.8 |
| **20** | 50 | 11.4 | 13.4 | 132 | 54 | 1684 | 48.1 | 4.6 | 246 | 94 | 164 | 57 | 7-9 | 14 | 3.8 | 4.8 |
| **21** | 51 | 11.6 | 13.4 | 132 | 55 | 1760 | 48.9 | 5.1 | 252 | 97 | 167 | 58 | 7-9 | 14 | 3.7 | 4.8 |
| **22** | 52 | 11.8 | 13.4 | 131 | 56 | 1838 | 49.7 | 5.5 | 258 | 99 | 171 | 59 | 7-9 | 15 | 3.5 | 4.8 |
| **23** | 53 | 11.9 | 13.4 | 131 | 56 | 1917 | 50.5 | 6.0 | 264 | 102 | 174 | 61 | 7-9 | 15 | 3.3 | 4.8 |
| **24** | 54 | 12.1 | 13.4 | 131 | 57 | 1999 | 51.2 | 6.5 | 270 | 105 | 178 | 62 | 7-9 | 15 | 3.2 | 4.8 |
| **COMM THIN REMOVAL** | | | | | 55 | 839 | | 2.7 | Thinned to: 24.0 X 24.0 Ft. | | | | | | | |
| **25** | 55 | 12.5 | 5.4 | 76 | 58 | 1283 | 53.0 | 4.5 | 181 | 65 | 109 | 38 | 7-9 | 15 | 8.7 | 1.4 |
| **26** | 56 | 13.0 | 5.4 | 76 | 60 | 1420 | 55.1 | 5.3 | 197 | 69 | 114 | 40 | 7-9 | 16 | 8.3 | 1.4 |
| **27** | 57 | 13.4 | 9.6 | 75 | 62 | 1565 | 57.2 | 6.2 | 213 | 74 | 120 | 42 | 7-9 | 16 | 7.9 | 1.4 |

age 30, and rate of growth was 5.4 rpi. Initial spacing was 9- by 9-feet with two projected thinnings (using user-specified spacing): one initially at 4.2 inches (18- by 18-feet spacing), and the second at 12.1 inches in diameter (24- by 24-feet spacing). The output is given in a year by year summary. After “Year 0” the stand was thinned to a spacing of 18- by 18-feet removing 403 trees per acre. Yearly updates of stand conditions are reported. After “Year 24,” at stand age 54, and mean diameter 12.1 inches, a second thinning removed 55 trees per acre and the final spacing was 24- by 24-feet. The table ends in “Year 27” with a mean stand diameter of 13.4. If no thinning had taken place in this example the resulting average stand diameter would have been 7.7 instead of 13.4 inches.

## *Model Validation*

The model results were validated using data from four sets of inventory and permanent growth plots in thinned and unthinned stands. The data used for validation include average density (trees per acre), number of years to last measurement, and average beginning diameter. This data was entered into the BPPP to calculate growth. The computed ending diameter was then compared to the measured mean diameter and percent error was calculated. For thinned stands, the measurement periods went from the time of thinning to the final inventory. For the unthinned plots, the measurement period ran from age 0 (dbh) to the age of the stand at final measurement. To validate, the actual average diameters were compared to those predicted by the model. Each line in tables 5 to 8 represents an individual stand and a model prediction for that stand.

The first set of data came from permanent growth plots on the Payette NF (Unpublished data on file at the Supervisors Office, Payette National Forest, McCall, Idaho. 2003a). These 61 plots contained mixed species and pure stands of ponderosa pine. They were thinned then re-measured 12 to 21 years later. The average thinned spacing ranged from 13.5 to 28.7 feet. Comparing the computed

**Table 5**—Summary of actual versus predicted diameter growth for a 12 to 21 period on 61 thinned permanent growth plots of Payette NF ponderosa pine and mixed stands using the Boise-Payette model. Percent growth error was calculated according to (predicted diameter - ending diameter)/ending diameter. The $r^2$ value for actual diameter vs. predicted diameter is 0.91.

| Species | Number of stands | Trees/acre | Spacing (ft) | Number of years for run | Diameter spread (in) | Average dbh (inches) Initial | Ending | Predicted | Percent error (%) |
|---|---|---|---|---|---|---|---|---|---|
| PP | 34 | 85 - 213 | 13.5 - 22.6 | 15 | 3.0 - 23.3 | 7.2 | 11.4 | 11.3 | –0.9 |
| PP,DF | 10 | 67 - 200 | 14.8 - 25.5 | 15 | 3.5 - 22.9 | 8.0 | 11.5 | 11.8 | 2.6 |
| PP,DF | 3 | 113 - 167 | 16.2 - 19.6 | 12 | 4.3 - 19.0 | 11.8 | 12.8 | 13.7 | 7.0 |
| PP,DF | 1 | 93 | 21.6 | 21 | 7.7 - 27.4 | 14.8 | 18.2 | 17.5 | –3.8 |
| PP,DF,LP | 1 | 167 | 16.2 | 15 | 3.7 - 17.2 | 8.9 | 11.9 | 11.8 | –0.8 |
| PP,WL | 1 | 213 | 14.3 | 15 | 5.3 - 11.2 | 4.7 | 8.9 | 9.4 | 5.6 |
| PP,LP | 1 | 180 | 15.6 | 15 | 4.0 - 17.1 | 8.2 | 12.7 | 11.3 | –11.0 |
| PP,GF | 1 | 140 | 17.6 | 15 | 7.2 - 16.2 | 5.5 | 10.3 | 10.8 | 4.9 |
| PP,WL,GF | 1 | 160 | 16.5 | 15 | 4.4 - 9.8 | 5.3 | 9.6 | 10.4 | 8.3 |
| GF,DF | 4 | 53 - 127 | 18.5 - 28.7 | 15 | 6.7 - 27.1 | 15.1 | 17.0 | 17.1 | 0.6 |
| ES,WL | 2 | 100 - 127 | 18.5 - 20.9 | 15 | 5.5 - 20.0 | 12.0 | 14.0 | 14.6 | 4.2 |
| ES | 1 | 87 | 22.4 | 15 | 9.5 - 16.8 | 11.9 | 13.6 | 15.3 | 12.5 |
| ES,DF,PP,GF,WL | 1 | 147 | 17.2 | 15 | 4.1 - 13.1 | 3.7 | 8.9 | 9.7 | 9.0 |
| Average across all stands | 61 | 53 - 213 | 13.5 - 28.7 | 12 - 21 | 3.0 - 27.4 | 8.3 | 12.0 | 12.1 | 0.8 |

**Table 6**—Actual versus predicted diameter growth on 24 permanent control growth plots of Payette NF ponderosa pine and mixed stands using the Boise-Payette model. These untreated stands are control plots for the treated stands in table 5. Percent error was calculated according to (predicted diameter - ending diameter)/ending diameter. The $r^2$ value for actual vs. predicted diameter is 0.97.

| Species | Trees/acre | Spacing (ft) | Number of years | Diameter spread (in) | Average dbh (in) Initial | Ending | Predicted | Error (%) |
|---|---|---|---|---|---|---|---|---|
| PP | 253 | 13.1 | 12 | 3.5-7.8 | 0 | 5.1 | 5.1 | 0.0 |
| PP | 367 | 10.9 | 11 | 3.5-7.4 | 0 | 5.0 | 4.7 | –6.0 |
| PP | 520 | 9.2 | 11 | 3.4-7.4 | 0 | 4.6 | 4.7 | 2.2 |
| PP | 167 | 16.2 | 11 | 3.4-5.4 | 0 | 4.4 | 4.7 | 6.8 |
| PP,DF,ES | 427 | 10.1 | 28 | 3.3-13.4 | 0 | 8.0 | 7.6 | –5.0 |
| PP | 380 | 10.7 | 14 | 3.5-8.4 | 0 | 5.6 | 5.8 | 3.6 |
| PP | 293 | 12.2 | 21 | 3.7-10.1 | 0 | 7.3 | 7.7 | 5.5 |
| PP,DF | 493 | 9.4 | 60 | 3.4-16.6 | 0 | 9.1 | 9.2 | 1.1 |
| PP | 327 | 11.5 | 11 | 3.5-7.0 | 0 | 4.6 | 4.7 | 2.2 |
| PP,GF,DF | 327 | 11.5 | 58 | 3.6-19.4 | 0 | 11.2 | 10.7 | –4.5 |
| PP,DF | 213 | 14.3 | 81 | 5.4-27.1 | 0 | 13.9 | 14.0 | 0.7 |
| PP,DF | 380 | 10.7 | 24 | 3.3-9.6 | 0 | 6.6 | 7.6 | 15.2 |
| PP | 347 | 11.2 | 12 | 3.5-11.4 | 0 | 5.1 | 5.1 | 0.0 |
| PP | 293 | 12.2 | 10 | 3.4-7.4 | 0 | 4.5 | 4.3 | –4.4 |
| PP | 320 | 11.7 | 29 | 3.4-12.0 | 0 | 7.9 | 8.6 | 8.9 |
| ES,WL,LP.DF | 527 | 9.1 | 69 | 3.6-17.7 | 0 | 9.3 | 9.3 | 0.0 |
| GF,DF,ES | 473 | 9.6 | 69 | 3.2-17.9 | 0 | 10.0 | 9.8 | –2.0 |
| PP | 573 | 8.7 | 26 | 3.5-11.1 | 0 | 6.0 | 6.6 | 10.0 |
| PP | 620 | 8.4 | 30 | 3.4-14.0 | 0 | 7.2 | 6.9 | –4.2 |
| PP,DF | 407 | 10.4 | 60 | 3.4-18.2 | 0 | 9.0 | 9.9 | 10.0 |
| PP,GF | 253 | 13.1 | 12 | 3.4-7.5 | 0 | 4.8 | 5.1 | 6.2 |
| PP,GF | 347 | 11.2 | 18 | 3.6-8.3 | 0 | 5.9 | 6.7 | 13.6 |
| PP,WL | 167 | 16.2 | 12 | 3.3-5.4 | 0 | 4.0 | 5.1 | 27.5 |
| PP,DF | 327 | 11.5 | 56 | 3.4-19.4 | 0 | 10.9 | 10.5 | –2.8 |
| Average | 366.7 | 11.4 | 31.0 | | 0 | 7.1 | 7.3 | 2.8 |

**Table 7**—Actual versus predicted diameter growth on 19 untreated mixed plots from Timber Inventory data collected on the Payette National Forest using the Boise-Payette model. The plot measurement interval ranges from 57 to 114 years. Percent error was calculated according to (predicted diameter - ending diameter)/ending diameter. The $r^2$ value for actual vs. predicted diameter is 0.90.

| Species | Trees/acre | Spacing (ft) | Number of years | Diameter spread | Average dbh (in) Initial | Ending | Predicted | Error (%) |
|---|---|---|---|---|---|---|---|---|
| GF,DF,PP,ES | 213 | 14.3 | 57 | 5.5 - 19.3 | 0 | 12.3 | 12.8 | 4.8 |
| DF,PP | 235 | 13.6 | 74 | 4.0 - 38.0 | 0 | 11.7 | 13.2 | 11.9 |
| DF | 263 | 12.9 | 97 | 7.0 - 40.1 | 0 | 11.8 | 13.6 | 15.1 |
| PP,DF,GF | 226 | 13.9 | 81 | 0.0 - 46.0 | 0 | 13.9 | 13.7 | –0.7 |
| DF,PP | 277 | 12.5 | 70 | 6.7 - 24.4 | 0 | 11.9 | 12.1 | 1.7 |
| AF,ES,LP,DF | 423 | 10.2 | 69 | 5.5 - 28.8 | 0 | 10.0 | 10.2 | 2.0 |
| GF,PP,DF | 143 | 17.5 | 77 | 5.9 - 34.1 | 0 | 16.8 | 16.2 | –3.0 |
| GF,DF,PP | 550 | 8.9 | 76 | 0.5 - 33.0 | 0 | 9.3 | 9.4 | 1.0 |
| GF,PP,DF | 363 | 11.0 | 82 | 0.0 - 25.1 | 0 | 11.4 | 11.4 | 0.0 |
| ES,LP,DF,WL,AF | 654 | 8.2 | 66 | 0.0 - 16.1 | 0 | 8.1 | 8.4 | 3.7 |
| GF,PP,ES,DF | 120 | 19.1 | 62 | 0.0 - 34.8 | 0 | 16.8 | 16.0 | –4.2 |
| GF,PP,DF | 255 | 13.1 | 68 | 0.0 - 23.0 | 0 | 11.5 | 12.4 | 7.8 |
| GF,DF,PP | 490 | 9.4 | 89 | 0.0 - 28.5 | 0 | 10.0 | 10.3 | 3.0 |
| GF,LP,ES,DF | 403 | 10.4 | 63 | 0.0 - 47.8 | 0 | 10.9 | 10.1 | –7.3 |
| GF,ES,DF | 242 | 13.4 | 109 | 1.0 - 38.8 | 0 | 14.1 | 14.5 | 2.8 |
| GF,DF | 502 | 9.3 | 70 | 1.0 - 23.0 | 0 | 10.1 | 9.6 | –5.0 |
| GF,ES,LP,WL | 647 | 8.2 | 59 | 0.0 - 25.4 | 0 | 7.6 | 8.2 | 7.9 |
| ES,AF,LP | 793 | 7.4 | 83 | 5.6 - 18.7 | 0 | 9.8 | 8.3 | –15.3 |
| GF,DF,ES,PP | 273 | 12.6 | 114 | 2.0 - 31.7 | 0 | 13.2 | 13.9 | 5.3 |
| Average | 372.2 | 11.9 | 77.2 | | 0 | 11.6 | 11.8 | 1.7 |

**Table 8**—Actual diameter growth on 18 treated ponderosa pine permanent growth plots on the Boise National Forest is compared to predicted growth using the Boise-Payette model. Percent error was calculated according to (predicted diameter-ending diameter)/ending diameter. The $r^2$ value for actual vs. predicted diameter is 0.96.

| Species | Trees/acre | Spacing (ft) | Number of years | Diameter spread | Average dbh (in) Initial | Ending | Predicted | Error (%) |
|---|---|---|---|---|---|---|---|---|
| PP | 380 | 10.7 | 14 | 3.4-7.4 | 0.0 | 5.0 | 5.8 | 16.0 |
| PP | 480 | 9.5 | 15 | 4.8-18.4 | 5.1 | 7.2 | 7.2 | 0.0 |
| PP | 140 | 17.6 | 20 | 6.9-14.3 | 5.8 | 11.7 | 12.0 | 2.6 |
| PP | 440 | 10.0 | 20 | 5.5-14.4 | 4.6 | 8.7 | 7.8 | –10.3 |
| PP | 220 | 14.1 | 15 | 4.4-11.6 | 5.6 | 9.1 | 9.6 | 5.5 |
| PP | 340 | 11.3 | 15 | 4.5-10.8 | 5.8 | 8.3 | 8.4 | 1.2 |
| PP,DF | 300 | 12.1 | 20 | 4.2-14.2 | 5.2 | 8.6 | 9.1 | 5.8 |
| PP | 380 | 10.7 | 20 | 5.0-10.8 | 4.7 | 8.0 | 8.3 | 3.8 |
| PP | 280 | 12.5 | 12 | 3.5-5.8 | 0.0 | 4.5 | 5.1 | 13.3 |
| PP | 160 | 16.5 | 9 | 3.1-5.7 | 0.0 | 3.9 | 3.8 | –2.6 |
| PP | 220 | 14.1 | 12 | 7.0-11.1 | 5.0 | 8.3 | 8.9 | 7.2 |
| PP | 140 | 17.6 | 10 | 3.4-4.9 | 0.0 | 4.3 | 4.3 | 0.0 |
| PP | 80 | 23.3 | 9 | 3.0-5.3 | 0.0 | 4.0 | 3.8 | –5.0 |
| PP | 120 | 19.1 | 12 | 5.0-8.3 | 4.5 | 8.8 | 9.6 | 9.1 |
| PP | 60 | 26.9 | 12 | 8.2-8.8 | 4.3 | 8.6 | 9.4 | 9.3 |
| PP | 60 | 26.9 | 9 | 3.2-5.2 | 0.0 | 4.3 | 3.8 | –11.6 |
| PP | 120 | 19.1 | 12 | 5.2-9.8 | 4.2 | 8.2 | 9.3 | 13.4 |
| PP | 80 | 23.3 | 11 | 3.7-5.4 | 0.0 | 4.4 | 4.7 | 6.8 |
| Average | 222.2 | 16.4 | 13.7 | | 3.0 | 7.0 | 7.3 | 2.9 |

stand growth output to the Payette permanent growth plot data revealed the model did a very good job of predicting stand growth in thinned stands, with an error between predicted and observed data of less than one percent (table 5).

The second set of plots used for validation was a group of 24 permanent growth plots from the same area (Unpublished data on file at the Supervisors Office, Payette National Forest, McCall, Idaho. 2003b). These had similar composition but they were unthinned control plots. Average spacing in these plots was between 9.1 and 16.2 feet. Comparison of the computed diameter to the actual measured diameter resulted in a percent error of less than 3 percent (table 6).

The third set of data from the Payette NF inventory plots contained 19 stands of mixed composition of which 11 plots contained ponderosa pine (Unpublished data on file at the Supervisors Office, Payette National Forest, McCall, Idaho. 2003c). None were pure ponderosa pine. The other species were Douglas-fir, grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt. var. *lasiocarpa*), western larch (*Larix occidentalis* Nutt.), and lodgepole pine. These stands have never been thinned. Again, the predicted average stand diameter was close to the actual measured stand diameter, with an error of less than 2 percent (table 7).

The final data set was from Boise NF permanent growth plots (Unpublished data on file at the Supervisors Office, Boise National Forest, Boise, Idaho. 2003). These 18 ponderosa pine stands were thinned to a range of 9.5 to 26.9 feet and re-measured anywhere from 9 to 20 years later (table 8). The results were similar to those from the Payette NF, with an error between observed and predicted dbh of less than 3 percent.

BPPP seems to work well in mixed forest types of southwest Idaho, even when ponderosa pine is a minor component of the stand. Stand density (range, 7.4 ft to 28.7 ft) and number of years of stand growth did not seem to affect the error.

It could be expected that the error would increase over time; however, the comparison showed little difference between short and long term projections. One stand grew for 109 years and the error was 2.8 percent. Another BPPP projection of 82 years predicted diameter exactly as observed. Also, there did not seem to be much difference in error when predicting small versus large average diameter stands (the initial diameter range was from 0 to 17.9 in). Comparing all four tables together, only 17 percent of the plots had an error between observed and predicted dbh greater than 10 percent, whereas 51 percent were within 5 percent of the observed diameter.

## *Other Growth Models*

It was shown by Basford and others (1991) that the SCPP model could effectively be used to predict ponderosa pine growth in other dry locations outside the southwest Idaho region. A direct comparison between actual growth data and predicted growth of ponderosa pine on 82 plots produced an $r^2$ of 0.98 in northern Arizona (Ronco and others 1985), the Blackhills of South Dakota (Edminster, C.B. 1988. [Unpublished data]. Fort Collins, CO: USDA Forest Service Rocky Mountain Research Station), central Oregon (Barrett 1982), Pringle Falls, Oregon (Cochran and Barrett 1999a), Lookout Mountain in Oregon (Cochran and Barrett 1999b), the Methow Valley in Washington (Cochran and Barrett 1998), and the Malheur NF in Oregon (Cochran and Barrett 1995). Only 10 percent of the plots showed an error of more than 10 percent. Sixty-eight percent of the plots were within 5 percent. The data is summarized by location in table 9.

Another computer modeling system called the Forest Vegetation Simulator (FV*S*) (Dixon 2006) also allows users to predict densities and diameters. It is reasonable for users to compare BKTHIN to FVS, but this should be done cautiously as these tools have different purposes with different levels of input. The FVS is a stand level, growth and yield system, using a variety of site and tree conditions within specific vegetative classes such as habitat type or site index within a variant region. Individual tree sample diameters are input, incremented, and compared with other tree samples in the plot. Each cycle interval (i.e. 10 years) is based on all tree samples in the plot. Tree specific information as well as stand summary information is reported.

**Table 9**—Actual versus predicted diameter growth (inches) on 82 ponderosa pine growth plots using the Salmon-Challis model. It was tested against the following studies: northern Arizona (Ronco and others 1985), Black Hills, South Dakota (Edmininster 1988), Pringle Falls, Oregon (Cochran and Barrett 1999), Lookout Mountain, Oregon (Cochran and Barrett 1999), Methow Valley, Washington (Cochran and Barrett 1998), and Malheur N.F., Oregon (Cochran and Barrett 1995). Percent error was calculated according to (predicted diameter - ending diameter)/starting diameter. The $r^2$ value for actual vs. predicted diameter is 0.98.

| Study area | Species | Number of stands | Range of trees/acre | Range of spacing (ft) | Number of years | Average dbh (in) | | | Error (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Initial | Ending | Predicted | |
| Arizona | PP | 12 | 61 - 681 | 8.0 - 26.7 | 10 | 6.6 | 8.5 | 8.2 | –3.5 |
| South Dakota | PP | 24 | 41 - 617 | 8.4 - 32.5 | 10 | 6.0 | 7.8 | 8.1 | 3.8 |
| Pringle Falls, Oregon | PP | 5 | 62.5 - 1000 | 6.6 - 26.4 | 35 | 2.0 | 9.0 | 9.1 | 1.1 |
| Lookout Mountain, Oregon | PP | 18 | 22 - 308 | 11.9 - 44.5 | 10 | 12.6 | 14.4 | 14 | –2.8 |
| Methow Valley, Washington | PP | 5 | 62.5 - 2387 | 4.3 - 26.3 | 30 to 35 | 4.3 | 9.1 | 10.0 | 9.9 |
| Malheur N.F, Oregon | PP | 18 | 56 - 455 | 9.8 - 27.5 | 4 to 10 | 8.7 | 9.8 | 10.0 | 2.0 |
| Average | PP | 82 | 22 - 2387 | 4.3 - 44.5 | | 7.8 | 9.9 | 9.9 | 1.0 |

Conversely, BKTHIN is a tree species level method, driven by spacing and diameter criteria that can be applied to broader regions. The average stand diameter is used as the initial input for the model and that diameter is incremented yearly over the planning horizon based on growth regression equations. Only stand summary information is reported at each one-year cycle.

A simple comparison was completed to see how both methods predict diameter and growth (diameter increment) for managed permanent growth plots on the Payette NF. These plots were initially inventoried in 1983 and 1988 with three to four 5-year re-measurements. The model was projected for a 15-20 year period using both BKTHIN and FVS. Table 10 displays the results of these projections as compared to the actual beginning data and the actual last re-measurement. Both methods started with the same initial QMD for a given plot. The diameter increment results are recorded for the actual, FVS, and BKTHIN, which are computed by calculating the change from the beginning to ending diameter and then dividing the result by the total years. Finally, all plot results were averaged by habitat type group. It may not be clear which method predicts most closely to actual. This is not a large data set, but both approaches appear to be reasonably similar. It would be interesting to conduct this comparison between FVS and the empirical approach reported here across a larger and more comprehensive data set.

# Management Application

The BPPP model is based on average size/density measurements. It allows thinning of stands to a given density, assuming growing stock is fairly uniform throughout the total area. It also uses crown ratio when considering whether the trees can fully respond to release. The model works best with even-aged stands, but data in table 7 suggest that it also works in uneven-aged stands. It predicts growth in unmanaged stands and has been found effective in pure or mixed stands of ponderosa pine, Douglas-fir, grand fir, subalpine fir, Engelmann spruce, western larch, and lodgepole pine.

BPPP can meet the needs of managers on the Boise and Payette NFs. The BKTHIN program can be used to maximize tree diameter through thinning at the right times before growth rates slow. It can also maximize stand volume by accepting slower growth rates but allowing more trees to better utilize the site.

**Table 10**—Actual versus predicted diameters (inches) from permanent plot data using FVS and BKTHIN are summarized by habitat type and number of years between measurements. "Average diameter increment" represents the average annual growth rate.

| | | Number | Ave. actual diameter | | Ave. predicted QMD 2003 | | Ave. diameter increment | | |
|---|---|---|---|---|---|---|---|---|---|
| Habitat type | Years projected | of stands | Start | End | FVS | BKTHIN | Actual | FVS | BKTHIN |
| Abgr/Acgl/Phma | 20 | 3 | 4.93 | 10.43 | 11.27 | 11.27 | 0.28 | 0.32 | 0.32 |
| Abgr/Libo | 15 | 3 | 8.90 | 12.60 | 11.73 | 11.40 | 0.25 | 0.19 | 0.17 |
| Abgr/Spbe | 15 | 3 | 9.60 | 13.67 | 12.37 | 11.70 | 0.27 | 0.18 | 0.14 |
| Abgr/Spbe | 20 | 8 | 5.39 | 12.64 | 12.24 | 11.76 | 0.37 | 0.33 | 0.32 |
| Abgr/Vagl | 15 | 3 | 7.37 | 11.03 | 11.10 | 10.63 | 0.24 | 0.25 | 0.22 |
| Pipo/Syal | 20 | 3 | 5.40 | 10.63 | 12.13 | 12.60 | 0.26 | 0.34 | 0.36 |
| Psme/Caru/Pipo | 15 | 3 | 9.30 | 13.13 | 12.23 | 11.90 | 0.26 | 0.20 | 0.17 |
| Psme/Caru/Pipo | 20 | 3 | 4.57 | 10.90 | 11.50 | 12.27 | 0.32 | 0.35 | 0.39 |
| Psme/Spbe | 15 | 3 | 7.17 | 11.00 | 10.97 | 11.40 | 0.25 | 0.26 | 0.28 |
| Psme/Syal/Pipo | 15 | 7 | 9.49 | 12.73 | 12.36 | 12.24 | 0.21 | 0.19 | 0.19 |
| Psme/Syal/Pipo | 20 | 3 | 8.83 | 13.20 | 12.43 | 12.90 | 0.22 | 0.18 | 0.21 |

When 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 timing of each intermediate harvest could result in reduced stand growth.

This model has several advantages. It can accurately predict diameter growth in forest stands of southwest Idaho. The input required to operate the model is very simple and easily obtained from National Forest stand inventory plots. BKTHIN is fast, easy to use and can be used by managers in the field. The methods reported above can be easily replicated for use in other regions.

With BKTHIN it is possible to manage diameter growth in even-aged stands by scheduling treatments to meet management objectives. However, as others have reminded us (Ernst and Knapp 1985, Leak 1981), we must continue to evaluate recommended stocking levels (stand density) 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. For a copy of the BKTHIN computer model, please contact one of the authors.

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