Sierra Cascade Intensive Forest Management Research Cooperative Proposal 09-01
Stand Density Index Study

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Title: Reevaluating Maximum Stand Density of Ponderosa Pine Stands in the Southern Cascades and Northern Sierra Nevada

Year Funded: 2009

Executive Summary:

Starting in 1944 and continuing through 1991, permanent plots in ponderosa pine and Jeffrey pine stands were established by U.S. Forest Service research scientists from the Pacific Southwest Research Station, personnel from the Pacific Southwest Region (R5), and researchers from the former Weyerhaeuser Company across northeast California. The common purpose of the original plot establishment was to determine the growth and yield of even-aged ponderosa pine or Jeffrey pine plantations in the region, although the specific objectives might vary for each installation. Therefore, these plots test various management treatments (Table 1). Some were studied for optimal stand density for conifer growth. Some were studied for the effect of understory vegetation control, with no, partial, and/or complete control of competing vegetation. Others plots, which were usually not replicated, were established for the purpose of constructing a yield table. Most studies were established in plantations ranging in age from 0 to 77 years at the time of plot establishment. Eleven plots were in natural stands ranging from 42 to 87 years old.

In 1995, Bill Oliver, a former Principal Silviculturist at the Pacific Southwest Research Station examined a self-thinning rule in even-aged ponderosa pine stands using these growth and yield plots. The self-thinning rule describes a relationship between size and density of organisms including even-aged plant populations. Because the slope of relationship was found to be -3/2 by Yoda et al. (1963), it is also called the -3/2 power rule or "Yoda's law." While ecologists were celebrating this discovery, people found that a forester had introduced the rule for forest stands 30 years earlier (Reineke 1933). He called it Stand Density Index, which is calculated:

$$SDI = TPA * (D/10)^{1.605}$$

Where: TPA = number of trees per acre, D = average stand diameter at breast height (quadratic mean diameter) in inches. Note that Reineke used a slope for the maximum stand density line of 1.605. A slope of 1.77, however, has been found to be a better fit for ponderosa pine data in this region (Oliver and Powers 1978, DeMars and Barrett 1987).

Applying the principle of "Reineke's stand density index (1933)", Oliver found that self-thinning started when stand density index reached 230, "as the beginning of a zone of imminent bark beetle mortality" and significant mortality occurred when SDI reached 365. This value was well below the

maximum SDI of 500 used in Region 5 or 429 used in Region 6 for the Forest Vegetation Simulators. However, Oliver (1995) argued that a SDI of 365 was the result of increased bark beetle activity during contemporary drought. Conventional self-thinning rules only included inter-tree competition as a cause.

Recent reviews of maximum stand density index for ponderosa pine in northern California based on the latest measurements on plots from 2004 to 2007 indicated that maximum SDI could have been higher than 365 as Oliver (1995) proposed. The proposal was to remeasure all the plots used in Oliver's paper (1995), add some plantation data available from California, and incorporate this new data into an analysis. An objective of this 2009 study is to determine whether Oliver's limiting SDI of 365 is still valid after 20 years of stand development.

2009 Measurements: Starting in 2000 and continuing through 2009, tree diameter and mortality on 121 of the plots listed in Table 1 were remeasured and quantified. The bulk of these plots were measured in 2009. Since the majority of these plots were established around 1970, these remeasurements represent 40 years of growth data. DBH was re-measured and mortality and over-all condition noted for the trees in 40 plots located at 12 sites in 2009, 20 plots in the Initial Spacing Study at Challenge Experimental Forest in 2007, 60 plots at 3 sites in 2005, and one plot at Dockwell in 2000 (Table 1). Previous measurements usually included dbh and tree condition for all trees in the plot and total height and height of live crown for 25-100% of the sampled trees in the plot. Inventories were usually conducted at five year intervals following plot establishment. The plots at Adin Pass, Antelope Mountain, Dockwell, Edson Creek, Hog Lake, Jelly Camp, Joseph Creek, Show Plantation, Sugar Hill, and Washington Mountain were established by Region 5 personnel and later transferred to PSW. Plots at KC Reservoir, Prattville, and Spaulding Butte were established by Weyerhaeuser researchers and transferred to PSW after the company terminated the project in 1987. With the exception of the Blacks Mountain Experimental Forest plot which was established by other PSW scientists, the rest of the plots were established by William Oliver. The plots have been appropriately maintained and each tree is numbered with a metal tree tag.

Preliminary results (a paper reporting these results can be found at the PSW office in Redding) indicated that stands at all sites, if not in all plots, experienced mortality (Table 1, Figure 1). The SDI reached over 200, close to the SDI value of 230 defined as the threshold for a zone of imminent bark beetle mortality, in at least one plot at each site suggesting that all plots should be included in the analysis.

After adding the 2000-2009 data, it was found that many plots exceeded the limiting SDI of 365 established by Oliver in 1995 (Figure 1). The SDI in some plots reached as high as 579 and yet massive mortality has not occurred in these plots. Size-density trajectories seem to have topped off when the stand SDI reached 500 in many plots.

Since Oliver felt the SDI value of 365 was a result of increased bark beetle activity during contemporary drought, the size-density trajectories were re-analyzed after eliminating the plots in which at least 25% of the trees were Jeffrey pine. This species is not as sensitive to bark beetles as ponderosa pine (Figure 2). It was found that only a few plots passed over the SDI value of 365 at Antelope Mountain, Challenge, KC Reservoir, and Prattville. Only one plot at Challenge showed mortality after exceeding the 365 value. Preliminary results indicated that all plots that exceeded a SDI value of 365 are plantations. The natural stands did not reach this line because of slow growth (Adin Pass) or heavy mortality (Edson Creek).

Values higher than 365, without heavy mortality, can be explained by bark beetle absence in the plots at Prattville and Challenge. The heavy mortality occurred due to normal competition in the high density plots when the SDI reached 500 at both sites. More interesting, it was observed that trees were killed by bark beetles in natural stands at Challenge but this type of mortality was not observed at the Prattville site.

There is no complete explanation for the heavy mortality on one of the plots at Antelope Mountain. This mortality was caused by both competition and bark beetles. Despite this heavy mortality, the SDI is still 572. The SDI for this plot was 584 in 1991 (plot establishment) and 637 in 2002. This is a very small plot (0.19 acre) and is surrounded by a treated stand and a road. These trees might not be influenced by the high SDI, as would have been expected, due to edge effect of the surrounding stands.

Plans are to measure additional intensively managed plots and natural stands. With additional funding or through in kind contributions, the Garden of Eden sites at Chester, Pondosa, and Jaws will be remeasured in 2010 and the resulting data, along with data from Levels of Growing Stock plots at Blue Mountain and Lookout Mountain which were remeasured in 2009, will be included with our data analysis. A hypothesis that plantation trees with early intensive management will grow at higher SDIs without mortality could be tested on plantations established on forest industry lands.