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Stocking Levels and Underlying Assumptions for Uneven-Aged Ponderosa Pine Stands

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Abstract

Many ponderosa pine stands have a limited number of size classes, and it may be desirable to carry very large trees through several cutting cycles. Large numbers of trees below commercial size are not needed to provide adequate numbers of future replacement trees. Under these conditions, application of stand density index (SDI) can have advantages over the use of Q-values in defining stocking levels. Calculation of SDI for uneven-aged stands must be done by summing values for individual trees or diameter classes. An example using SDI to derive stocking levels after partial cutting is presented.

Keywords: Stand density index, Q-values, uneven-age management, stocking levels.

Introduction

The amount of scientific information that can be directly applied to determining densities for managed ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.) stands of commercial size in the Pacific Northwest is limited at present. Mortality due to factors other than suppression is significant, and mountain pine beetle *(Dendroctonus ponderosae* Hopkins) is a primary cause of tree loss. The relation between mortality caused by mountain pine beetle and stand and tree characteristics is unclear. Tree size, distance between trees, tree vigor, and other factors all seem to be involved (Mitchell and Preisler 1991). Stocking-level curves for simple even-aged stands, where the upper level of the management zone is set to avoid problems with mountain pine beetle therefore are subject to controversy. Although management for uneven-aged stands of ponderosa pine has been practiced to varying degrees over the years, long-term studies examining mortality and growth of various sized trees under different regimes do not exist in the Northwest. Still, the silviculturist can arrive at appropriate residual stocking levels for uneven-aged stands by using some reasonable assumptions. This note outlines those assumptions and presents an example of their application.

Potential Problems With Q-Values

In classical uneven-age management where stands have a balanced all-age and all-size distribution, residual stand basal areas, desired maximum and minimum diameters, and diminution quotients (Q-values) are used in combination to define growing stock levels after stand entry. In theory, application of Q-values produces a curve of tree numbers as a function of diameter that describes a sustainable diameter distribution. The application of Q-values using 2- to 4-inch diameter classes to ponderosa pine stands presents some problems: The largest target diameter must be determined, and some stands have very large vigorous trees that perhaps should be retained, but the next largest trees are several inches smaller in diameter. Many ponderosa pine stands also have few size and age classes, and the trees needed to meet a Q-distribution over the whole range of commercial sizes are not present. Strict application of a high Q-value through

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the whole range of narrow diameter classes, if present, results in too many trees below commercial size. The stocking levels for these smaller diameter classes can be so high that the "slowness with which the reproduction stand develops is... discouraging..." (Meyer 1934). In addition, if different Q-values are used with the same maximum and minimum diameters and the same residual basal areas to describe the desired residual stands, the resulting stands have a different stand density index. This last point is probably not of practical importance, but it illustrates the possibility that balanced uneven-aged stands with the same residual basal area and range in diameters but differing in Q-values may not have the same site occupancy.

Tree Response to Stocking Levels

There are several reasons why uneven-age management is now being implemented on the lands administered by the Forest Service. One is that many people want to see ponderosa pine forests with large trees having yellow- or cinnamon-colored bark continually present on every acre. Ponderosa pine has a long life span. Observations after partial cutting indicate that trees with good crowns respond to increased growing space even when more than 250 years old. Dominant ponderosa pine also respond markedly to removal of adjacent subordinate trees (Barrett 1963). Individual ponderosa pine trees, even if long suppressed, can develop large diameters fairly rapidly if enough growing space becomes available (Barrett 1981, 1982). Stands with large-diameter trees can be created and maintained if stocking levels are chosen that sacrifice some stand productivity for individual tree growth (Barrett 1983). To provide the necessary growing space for the development of uneven-aged stands with large trees, sufficient site resources must be directed toward large trees. Only enough small trees should be kept to eventually provide replacements for the commercially sized trees. Keeping more than enough small trees may severely retard the growth of replacement trees, because the growth of these small trees is reduced by competition from one another as well as from the overstory (Barrett 1969, 1979).

Long and Daniel (1990) suggest that Reineke's (1933) stand density index (SDI) can be used to define stocking levels for uneven-aged stands and that the application of SDI can have advantages over the use of Q-values. In this note, stocking level curves for even-aged stands are presented that are defined as fractions of "full" or "normal" stocking. These curves are then used as an aid in defining stocking levels for uneven-aged stands. The procedures used are outlined and an example is provided. The example does not deal with regeneration, which may or may not occur depending on the plant association and other factors.

Stocking-Level Curves for Even-Aged Stands

Field observations of even-aged stands suggest that tree mortality due to mountain pine beetle remains at a low level until a certain stand density is reached. This critical density differs by site, and when this density is exceeded, mortality can become serious. The average size of the trees killed by mountain pine beetle is about the size of the average surviving tree. The stocking-level curves for even-aged stands (fig. 1) are empirical curves showing the maximum stocking levels that ponderosa pine stands can be expected to attain without a high probability of encountering serious mortality from mountain pine beetles. Better curves may be developed when more is known about the interactions between this insect and tree and stand conditions; These maximum stocking levels for managed stands can be expressed as fractions of the SDI for "normal" even-aged ponderosa pine stands, which is 365 (DeMars and Barrett 1987). When

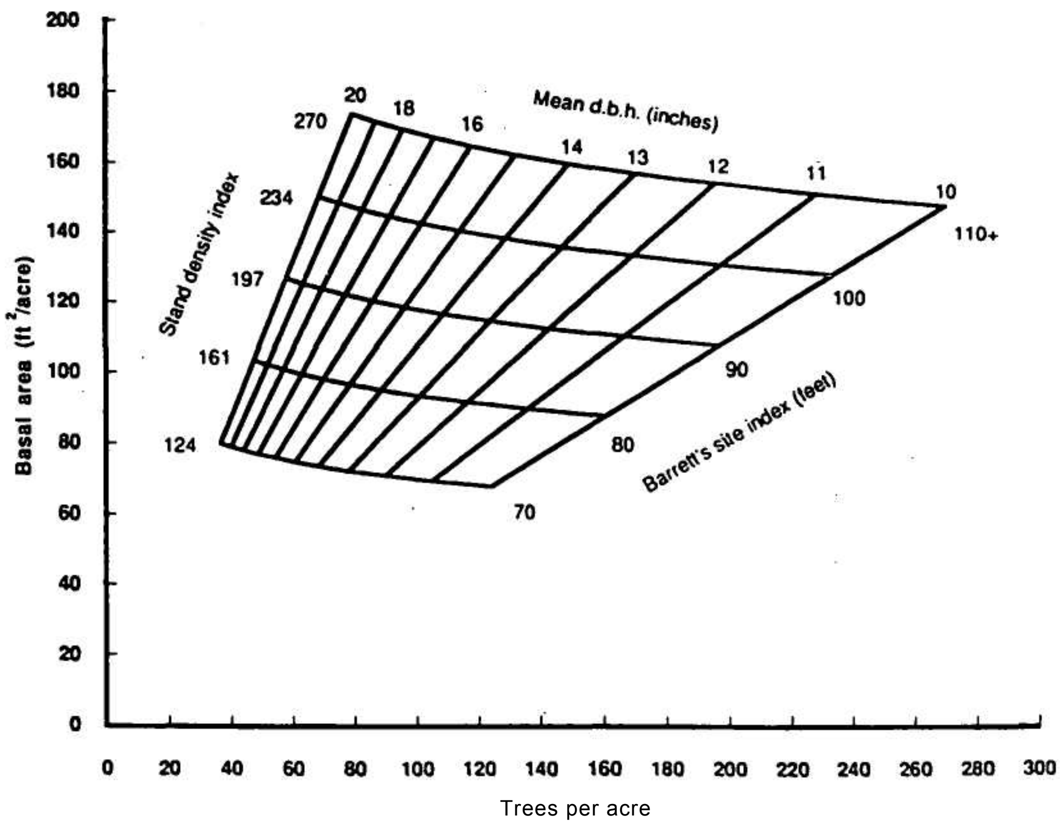

Figure 1—Empirical stocking-level curves for even-aged ponderosa pine showing the upper limit of the management zone (the maximum managed-stand stocking levels) as a function of Barrett's site index values.

expressed as a fraction of 365, the maximum managed-stand stocking levels (MSL) of figure 1 are related to Barrett's (1978) site index values (S) by,

$$MSL/365 = -0.36 + 0.01 (S) , \quad (1)$$

for site index values up to 110. For stands with site index values greater than 110, the upper limit of the management zone is set at an SDI value equal to 74 percent of 365 to avoid development of a suppressed class of trees.

Some Useful Equations

The relation between trees per acre (T/A) and the quadratic mean diameter (Dg) for normal even-aged stands is (Reineke 1933),

$$\log_e(T/A) = a - b(\log_e Dg). \quad (2)$$

SDI is the number of trees per acre defined by equation (2) when the Dg is 10 inches. For even-aged stands with normal diameter distributions,

$$SDI = (T/A)(Dg/10)^b, \quad (3)$$

$$T/A = SDI/(Dg/10)^b, \text{ and} \quad (4)$$

$$Dg = 10(SDI/(T/A))^{(1/b)}. \quad (5)$$

When coefficients a and b are defined by applying a least squares fit of appropriate data, SDI for a "normal" or "fully stocked" stand is determined by using these values for a and b in equation (2) with a value of 10 for Dg. In applying a least squares fit to determine values for b, it is important that stands of all sizes in the data set are at the limiting density level where competition-induced mortality exists. At times the term "maximum SDI" is used. Maximum SDI is determined by first adjusting the intercept value (a) so that the regression line skims the upper limits of the data points. This adjusted intercept value is then used with the previously defined value for b and a Dg of 10 inches to define this "maximum SDI." Reineke (1933) determined a slope of -1.605 for equation (2), apparently by plotting the data and drawing a line along the upper margin. He assumed this value for b was appropriate for all species. DeMars and Barrett (1987) found a slope of -1.7653 and an intercept of 9.9657 for a least squares fit of equation (2) with Meyer's (1961) original data. Oliver and Powers (1978) also found a slope of -1.77 for a least squares fit of equation (2) with data collected in a survey of dense, even-aged stands in northern California. A value for b of 1.7653 was used for calculations in this note.

For stands where the diameter distribution is not normal, an alternate expression for SDI is (Long and Daniel 1990),

$$SDI = \sum (DBH_i/10)^b, \tag{6}$$

where DBH_i is the diameter of the i_{th} tree in the stand and b is as previously defined. Equation (6) is the same expression as Curtis (1971) derived for Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) by using the tree-area ratio procedure.

Two systems for obtaining site index values for ponderosa pine are used in the Northwest. Meyer's (1961) system uses the height of the quadratic mean diameter of the crop trees and total age. Barrett's (1978) system uses the height of the tallest tree in a 1/5-acre plot and the age at breast height. Index ages are 100 total years for Meyer's system and 100 years at 4.5 feet for Barrett's system. The relation between the site index values of Barrett (1978) in feet (S) and the site index values of Meyer (1961) in feet(SI)is,[1]

$$S = 37.735 + 0.931451\,(SI)\,. \tag{7}$$

Determination of Stocking Levels

A good silvicultural prescription leaves the stand in better condition after treatment than before entry. One of the keys to a healthy stand is the proper level of vigorous growing stock. The following steps are suggested to determine growing stock levels for uneven-aged stands after stand entry:

1. Obtain the diameter distribution by size classes. One- or two-inch size classes or at times even 4-inch size classes are suitable. Calculate the SDI for each size class by using either equation (6) or (3). The slightly differing values obtained from the two equations are of no practical consequence. Sum the SDIs for each diameter class, or use equation (6) to get the SDI for the stand.

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[1] **DeMars, Donald J. 1988. Letter dated September 28 to Patrick H. Cochran. On file with: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1027 N.W.Trenton Avenue, Bend, OR 97701 [RWU 4152 files).**

2. Use Barrett's site index value for the stand and equation (1) to determine the maximum managed SDI the stand should have. If the available site index for the stand is Meyer's (1961) value, be sure to convert to Barrett's value by using equation (7) before applying equation (1). If the site index of Barrett is above 110 feet, the maximum managed stand SDI is 0.74 multiplied by 365, or 270. Because ponderosa pine exhibits a range in stocking levels for various site index classes, a lower maximum managed SDI than the one determined from the site index value may have to be used. From the table created in step 1, consider how the stocking is distributed by diameter class. For occupied sites, the fraction of the stand occupied by each diameter class is the SDI of that diameter class divided by the SDI of the stand. For timber growth, there is no point in having a large portion of the site occupied by trees below commercial size, as will be the case if a high Q-value is applied across narrow diameter classes. Below the commercial size limit, only enough trees are needed to provide replacements for the commercial-sized trees when they are removed during future entries. Some stands will need considerable tending in the precommercial size classes to shift the resources of the site from large numbers of small trees, which will never all grow to salable size, to the larger size classes.

3. Determine what the stand should look like after entry and after precommercial thinning is accomplished. One possible starting point is to assume that the stand SDI after treatment should be about two-thirds of the maximum managed stand SDI. Next, decide how this stocking should be distributed across the various size classes. It is helpful to group the size classes such that four or more groups are above commercial size, depending on the range of diameters, and two or more groups are below commercial size; then calculate the SDI of each group by adding the SDIs of each diameter class within that group. Do some careful thinking about the number of trees needed in the precommercial size classes. One reasonable way to do this is to first ignore the stocking in the precommercial size classes. Next, set the SDI for the stand wanted after treatment and divide this SDI by the number of groups in the commercial size class. Use this average SDI to determine the number of trees that would be left in the group with the smallest commercial sizes after treatment. From this preliminary estimate of the numbers of trees in the group with the smallest commercial sizes, make some estimates of the number of trees needed in the precommercial size classes to provide enough trees in the smallest commercial-sized group at future entries. This estimate will involve some guesses about mortality in the small-tree sizes and perhaps some assumptions about small-tree growth rates, but leaving too many small trees will be avoided. To more firmly set stocking levels in the commercial-sized groups, calculate the SDI of the precommercial-sized leave trees and subtract this SDI from the target stand SDI after treatment. Distribute the remaining SDI among the commercially sized groups. A starting point here is to assign equal amounts of stocking to each commercially sized group. Consider removing trees in each of these diameter classes to reduce the SDI of that group to the defined level. If some groups are already below the desired level, more trees should be left in adjacent groups. Because one of the goals of uneven-age management is to produce big trees, think carefully about cutting large trees with vigorous crowns in all cases but particularly when the stocking in the next group of smaller trees is lower than the desired level. At this point, it might be worthwhile to examine the number of trees in the group with the smallest commercially sized trees and see if too many trees of noncommercial size have been left. If so, the number of these trees can be reduced and the above process can be repeated.

4. Using prognosis (Wykoff and others 1982) or some other stand projection technique, estimate how long it will take for the stand to grow after treatment back to the maximum managed-stand stocking level. If the estimated length of time is not a reasonable cutting cycle, you might wish to raise or lower the stocking level after treatment and again project the stand forward in time.

An Example

The stand used as an example (table 1) has been divided into 1-inch diameter classes and seven groups. Commercial sizes are considered to start with the 11 -inch class, so there are five groups of commercially sized trees and two groups with trees below commercial size. These diameter classes, groupings, and the selected commercial size are somewhat arbitrary and could be changed. The stand has a site index of 102 feet (Barrett 1978), so the upper limit of stocking for a managed stand should be 66 percent (from equation 1) of an SDI of 365, or 241. After treatment, a reasonable first estimate of residual stand SDI would be 67 percent of 241, or 161. Suppose this stand is to be treated now. As a starting point in estimating the necessary stocking for the precommercial size classes, assume that all the residual stocking is to be in commercially sized trees and that the stocking is to have a fairly even distribution among all groups of commercially sized trees. Dividing 161 by 5 (the number of commercially sized groups) results in an SDI for each group of 32. The lower group of commercially sized trees has an SDI of 31. So we can assume that the number of trees in this class after treatment is close to correct. We therefore can take the number of trees in this class and use it as a guide to estimate the necessary number of trees in the noncommercial size classes (table 2). If the lowest commercial sized group would have had an SDI greater than 31, a number of trees would have to be removed to lower the SDI to the estimated level; these residual tree numbers could then be used as a guide for the lower size classes. If the lowest commercially sized group has an SDI lower than 32, equation (4) could be used to estimate the number of needed trees. These estimated tree numbers could then be used as guides to estimate the number of trees needed in the noncommercial size classes. After estimates are made of the desired number of trees in the noncommercial size classes after treatment, the approximate SDI for these two groups is recalculated by multiplying the current SDI in each size class by a fraction equal to the estimated number of trees after treatment and dividing by the current number of trees. Totaling the SDIs for these diameter classes leaves SDIs of 8.9 and 26.4 for the two groups of the smallest size classes (table 2). Subtracting the total of 8.9 plus 26.4 (35.3) from 161, the target SDI after treatment, leaves an SDI of 125.7 for the commercial sizes. If this stocking is spread over the five commercial-sized groups equally, each of the groups would have a residual stocking equivalent to 25. Two of these five groups currently have SDIs below 25 and three have SDIs greater than 25. Reducing the SDIs of the group containing 11 - to 15-inch trees to 25 and the group with 21 - to 25-inch trees to an SDI of 36.6 leaves the total SDI for the five groups at 125. About 2,850 board feet would be removed. There are other ways to lower the stocking to obtain the same target density, but vigorous trees should be left as growing stock and the choices made should probably favor leaving vigorous large trees.

Discussion

Several tenuous assumptions have been used in this note. Figure 1 is considered a reasonable guide to stocking for even-aged ponderosa pine stands in the Northwest. Practicing foresters may want to raise or lower the levels shown in figure 1. Because the curves are empirical, there may be good reasons for changing these levels for some areas if field observations support change. The level of stocking where full or nearly full site occupancy occurs for ponderosa pine varies within the same site class (Hall 1971), and the levels for figure 1 should be lowered for some plant associations where the

Table 1—Trees per acre and SDI by 1-inch diameter classes before treatment for a ponderosa pine stand

D.b.h. class	By class		By group	
	T/A[a]	SDI[b]	Basal area	SDI[b]
Inches			*Ft²/acre*	
≤2	250	6.5	8.1	19.3
3	19	2.9		
4	16	3.8		
5	18	6.1		
6	19	8.7	18.4	35.3
7	12	7.1		
8	12	8.9		
9	7	6.3		
10	4	4.3		
11	6	7.6	18.1	31.0
12	3	4.4		
13	3	5.1		
14	5	9.6		
15	2	4.3		
16	3	7.2	8.3	13.4
17	0	0		
18	1	3.0		
19	1	3.2		
20	0	0		
21	2	7.7	33.6	50.5
22	1	4.2		
23	3	13.6		
24	3	14.6		
25	2	10.4		
26	0	0	13.9	19.9
27	0	0		
28	2	12.7		
29	0	0		
30	1	7.2		
>30.9	3	29.9	22	29.9
Total	398	199.0	122.4	199.0

[a] T/A represents trees per acre.

[b] SDI represents stand density index.

Table 2-Possible trees per acre and SDI for the stand in table 1 immediately after treatment

D.b.h. class	By class		By group	
	T/A[a]	SDI[b]	Basal area	SDI[b]
Inches			*Ft²/acre*	
≤2	14	0.4		
3	13	2.0	4.2	8.9
4	12	2.8		
5	11	3.7		
6	10	4.6		
7	9	5.3		
8	8	5.9	17.4	26.4
9	7	6.3		
10	4	4.3		
11	4	5.0		
12	3	4.4		
13	2	3.4	14.5	24.8
14	4	7.7		
15	2	4.3		
16	3	7.2		
17	0	0		
18	1	3.0	8.3	13.4
19	1	3.2		
20	0	0		
21	1	3.8		
22	1	4.2		
23	2	9.1	24.8	37.2
24	2	9.7		
25	2	10.4		
26	0	0		
27	0	0		
28	2	12.7	13.9	19.9
29	0	0		
30	1	7.2		
>30.9	3	29.9	22	29.9
Totals	122	161.0	105.1	161.0

[a] T/A represents trees per acre.

[b] SDI represents stand density index.

productivity is low. One estimate of how much the levels of figure 1 should be lowered for some plant associations can be made from the productivity information given in the plant association guides (Hall 1973, Volland 1985). Consider the upper limits of figure 1 to correspond with the highest productivity for a given site index in the guides. Use this productivity value as the denominator and the productivity value of the plant association in question as the numerator in determining an adjustment fraction. Multiply the level in figure 1 by this fraction to define the upper limit of stocking for that plant association. In areas where mountain pine beetles are not a problem, the temptation will be to raise these levels for site index values of Barrett below 110 feet, and caution is urged in these cases. Increasing the upper limit of the management zone to an SDI greater than 74 percent of 365 probably will result in a suppressed class of trees and is not recommended. Use of the levels in figure 1 for defining stocking levels for uneven-aged stands assumes that insect dynamics for even- and uneven-aged stands are the same. This assumption probably is not true, but little is known about differences in the behavior of mountain pine beetle in even- and uneven-aged stands. Further, growth rates of small trees are assumed to be rapid enough to supply a reasonable rate of replacement for larger trees removed in future cutting cycles. Small long suppressed ponderosa pine trees will respond to release when the overstory is removed and the understory is thinned. Less response is to be expected when an overstory is retained. Field examinations of height growth in stands to be treated may be helpful in deciding if the growth rates of small trees will be adequate.

The example presented does not deal with regeneration. The amount of regeneration occurring within a given range of stand densities during any given time period differs greatly between plant associations. For some plant associations, sufficient regeneration will occur for cases similar to the above example; for others, lower residual densities and the greater exposure of mineral soil accompanying the creation of these densities will be necessary to obtain the needed regeneration.

Literature Cited

Barrett, James W. 1963. Dominant ponderosa pine do respond to thinning. Res. Note PNW-9. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 8 p.

Barrett, James W. 1969. Crop-tree thinning of ponderosa pine in the Pacific Northwest. Res. Note PNW-100. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.

Barrett, James W. 1978. Height growth and site index curves for managed even-aged stands of ponderosa pine in the Pacific Northwest. Res. Pap. PNW-232. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

Barrett, James W. 1979. Silviculture of ponderosa pine in the Pacific Northwest: the state of our knowledge. Gen. Tech. Rep. PNW-97. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 106 p.

Barrett, James W. 1981. Twenty-year growth of thinned and unthinned ponderosa pine in the Methow Valley of northern Washington. Res. Pap. PNW-286. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.

Barrett, James W. 1982. Twenty-year growth of ponderosa pine saplings thinned to five spacings in central Oregon. Res. Pap. PNW-301. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

Barrett, James W. 1983. Growth of ponderosa pine poles thinned to different stocking levels in central Oregon. Res. Pap. PNW-311. Portland OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 9 p.

Curtis, Robert O.1971. A tree area power function and related stand density measures for Douglas-fir. Forest Science. 17(2): 146-159.

DeMars, Donald J.; Barrett, James W. 1987. Ponderosa pine managed-yield simulator: PPSIM user's guide. Gen. Tech. Rep. PNW-GTR-203. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 36 p.

Hall, Frederick C. 1971. Some uses and limitations of mathematical analysis in plant ecology and land management. In: Patil, G.P.; Pielou, E.C.; Waters, W.E., eds. Many species, populations, and systems analysis: Statistical ecology. University Park, PA: The Pennsylvania State University Press: 377-395. 3 vol.

Hall, F.C. 1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. R6-8200-1. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 46 p.

Long, James N.; Daniel, Theodore W. 1990. Assessment of growing stock in uneven-age stands. Western Journal of Applied Forestry. 5(3): 93-95.

Meyer, Walter H. 1934. Growth of selectively cut ponderosa pine forests of the Pacific Northwest. Tech. Bull. 407. [Location of publisher unknown]: U.S. Department of Agriculture. 64 p.

Meyer, Walter H. 1961. Yield of even-aged stands of ponderosa pine. Revised. Tech. Bull. 630. [Location of publisher unknown]: U.S. Department of Agriculture.

Mitchell, Russel G.; Preisler, Haiganoush K. 1991. Analysis of spatial patterns of lodgepole pine attacked by outbreak populations of mountain pine beetle. Forest Science. 37(5): 1390-1408.

Oliver, William W.; Powers, Robert F. 1978. Growth models for ponderosa pine. I: Yield of unthinned plantations in northern California. Res. Pap. PSW-133. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 21 p.

Reineke, L.H. 1933. Perfecting a stand density index for even-aged forests. Journal of Agricultural Research. 46(7): 627-638.

Volland, Leonard A. 1985. Plant associations of the central Oregon pumice zone. R6-ECOL-104-1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 138 p.

Wykoff, William R.; Crookston, Nicholas L; Stage, Albert R. 1982. User's guide to the stand prognosis model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112p.

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