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Log and Lumber Grades as Indicators of Wood Quality in 20- to 100-Year-Old Douglas-Fir Trees from Thinned and Unthinned Stands

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Abstract

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This report examines the differences in wood characteristics found in coastal Pacific Northwest Douglas-fir (*Pseudotsuga mensziesii* (Mirb.) Franco) trees harvested at the age of 70 to 100 years old to wood characteristics of trees harvested at the age of 40 to 60 years. Comparisons of differences in domestic log grades suggest that the proportion of log volume in the higher grades (Special Mill and No. 2 Sawmill) increased with both stand age and tree size. Simulation of lumber grade yields based on log characteristics suggests that yields of higher grades of lumber increased until about age 60 to 70, and then leveled off over the rest of the age range examined in this analysis. We included structural lumber products in the analysis but not higher value appearance grade products, and some evidence suggests that yields of these products might have begun to increase in the oldest trees. The analysis also showed that the younger trees had larger branches and more juvenile wood, possibly because they had been grown in stands that received a higher level of early stand management than the older trees. If these young trees were grown to the ages of 70 to 100, they likely would not produce the same log and lumber grade yields found in the older trees we examined.

Keywords: Wood quality, log grade, lumber grade, thinning, Douglas-fir, *Pseudotsuga mensziesii*, ecosystem management, sustainable forestry.

Contents

Introduction

In recent years, most landowners in the coastal Pacific Northwest have begun to place greater emphasis on conserving biodiversity in their management practices. There are, however, important distinctions in the objectives of the various landowners. Whereas most federal lands and some other public lands are now managed primarily to maintain or restore ecological function, with wood production being a secondary objective, wood production is still the primary objective for most private landowners of industrial and large nonindustrial land. There are many variations on these broad themes, but in general, this divergence in objectives results in relatively long rotations to promote old-forests characteristics on public land and relatively short rotations to enhance the economic returns from wood production on large private land holdings.

Most managers of industrial and large nonindustrial land holdings have adopted stand management practices that involve planting and precommercial thinning[1] followed by either a commercial thinning or clear felling by about age 40. The first commercial entry is highly dependent on market conditions. It may replace a precommercial thinning at about age 20 if pulp or chip markets are good, or it may not occur until about age 40, but in most cases, clear felling usually occurs no later than age 60. Port Blakely Tree Farm in Seattle, Washington, is a moderate size, private owned company that uses a different strategy. On some of the Port Blakely land, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is managed on 70- to 100-year rotations under silvicultural regimes that may involve multiple thinnings. The regimes used by Port Blakely are similar to management activities anticipated for some USDA Forest Service and USDI Bureau of Land Management (BLM) land designated as “matrix” or during the period when active management is allowed in “late-successional reserves” under the Northwest Forest Plan (NWFP) for the recovery of the northern spotted owl (USDA and USDI 1994).[2] These management techniques also might interest other landowners, of both large and small parcels, who want to create stand characteristics that differ from those found in typical industrial plantations but who still consider timber harvest an important land management objective (Curtis and others 1998).

The analysis described here was undertaken as a cooperative project between Port Blakely Tree Farm and the USDA Forest Service, Pacific Northwest (PNW) Research Station. We evaluated those differences in wood characteristics likely to exist in Douglas-fir stands managed on shorter (40- to 60-year) and longer (70- to 100-year) rotations. Potential log and lumber quality for trees removed as early as 20 years, which might be expected during early commercial thinning, and trees removed at up

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[1] Under some market conditions, thinned material is sold for chips, whereas under others it is left on the site.

[2] The matrix land allocation under the Northwest Forest Plan for the recovery of the northern spotted owl (NWFP) “...is the area in which most timber harvest and other silvicultural activities will be conducted.” Late-successional reserves are intended to “...maintain a functional, interactive, late-successional and old-growth forest ecosystem. They are designed to serve as habitat for late-successional and old-growth related species including the northern spotted owl.”

to 100 years are considered. Economic analysis is not performed in this report because (1) the economics of wood production is not a primary concern under the NWFP, and (2) firms interested in this information will conduct their own economic analyses using proprietary financial data. This report should, however, provide sufficient information about wood characteristics for those interested in conducting economic analyses.

Data for the analysis came from two sources: (1) new data, collected from a sample of trees harvested from two Port Blakely thinning trials in naturally regenerated Douglas-fir stands on site II+ (King 1966) land in southwestern Washington and (2) existing data drawn from a database of tree, log, and lumber characteristics maintained by the Ecologically Sustainable Production (ESP) of Forest Resources team of the PNW Research Station (Stevens and Barbour 2000). The trees used for this analysis came from studies conducted by the ESP team in collaboration with a consortium of public and private landowners known as the Stand Management Cooperative (SMC) (see Fahey and others 1991). These trees are referred to as the SMC trees.

Curtis (1995) and Stinson (1999) give details about the stand characteristics and the treatment history for the Port Blakely thinning trials. The older installation, designated by Port Blakely as XT-1, was established in a 47-year-old stand in 1948 and harvested at age 95. Curtis (1995) characterizes the thinning regime as light. The younger installation, known as XT-7, was established in a 42-year-old stand in 1958 and harvested at age 80. Curtis (1995) characterizes the treatment of this installation as a heavy thinning. Trees were removed from the Port Blakely thinning trials in summer 1996 to determine various wood characteristics. The sample of SMC trees represents trees that are about the same age as the Port Blakely trees. In addition, the SMC trees include a sample of younger trees intended to provide a comparison with current management practices being used on private land in western Washington and Oregon.

Objectives

The objectives of this analysis were developed to provide information that is useful to both public and private resource managers interested in understanding the influence of stand age and management history on wood characteristics. The objectives were to:

1. Make qualitative comparisons of the characteristics of trees grown on Port Blakely's XT-1 and XT-7 thinning trials to trees in various age classes that represent typical management practice on industrial forest land in western Washington and Oregon (SMC trees). We compared:

    a. Log and lumber grade yields of thinned and unthinned portions of each XT thinning trial

    b. The characteristics of trees grown on the XT thinning trial to those of SMC trees of similar ages

    c. The characteristics of both the Port Blakely trees and older SMC trees (80 to 100 years) to those of younger SMC trees (20 to 60 years)

2. Develop a better understanding of the likely wood characteristics of trees grown under the longer rotation mandated for some lands under the NWPF for matrix land (USDA and USDI 1994).

Methods

The three measures of wood quality considered in this analysis are (1) log grade, (2) visual lumber grades, and (3) machine stress-rated (MSR) lumber grades. These measures were chosen because they can be evaluated directly to compare product potential of each group, and because price series are readily available for each product (Anderson 2000, Barr 1998, Warren 1998), thereby making it easy for others to conduct economic analyses by using the product yield information provided in this analysis. Only structural products were considered because self-pruning does not typically occur in Douglas-fir stands until age 60 to 80 (Kachin 1940), and thus even the oldest trees used in this analysis had insufficient time to produce appreciable amounts of clear wood.

The available data sets are not ideal for this analysis because many of the trees were originally collected for other purposes. Not all of the records for the trees included in the analysis contained all the information needed to produce grades under all three systems. The data sets are, however, adequate to make reasonable estimates of log grades by using techniques developed by Christensen (1997). Christensen's (1997) techniques use diameter at each buck point, measurements of branch size by using a modified height pole and caliper, and estimations of growth rate. Simulation of lumber grade yield is also possible by using regression models developed by Fahey and others (1991). Although estimated log grades and simulated lumber yields do not provide an exact description of wood characteristics in these trees, they do allow reasonable comparisons among the various age classes and management intensities.

Source of Data

At each of the two Port Blakely installations, 25 sample trees were selected systematically across the full range of diameters present on the unthinned and thinned permanent sample plots. This process resulted in selection of 50 trees from each thinning trial for a total of 100 Port Blakely trees. An additional 289 trees were selected from two earlier SMC studies (Barbour 1995,[3] Fahey and others 1991) by using the ESP tree quality database (table 1).

The criteria used for selecting an SMC tree were that (1) tree age (from 21 to 100 years) and (2) sufficient data (enough data had to be available about a tree to estimate the log or lumber grades used in the analysis). The two previous SMC studies included trees from 20 locations throughout western Washington and Oregon. The objectives of these studies and the tree selection criteria were similar in that they focused on site class I or II land and trees grown in either natural stands or plantations managed for rapid wood volume production. We believe this sample represents the existing resource on private land, but most Forest Service and BLM land has a much lower site class. Consequently, site class should always be considered before extrapolating results to federal ownerships. We believe that the similarity in sites, management history, and selection criteria made it reasonable to combine trees from the two studies. Trees included in these two studies were selected systematically to represent the range of variation in diameter and branch size and should not be regarded as random samples. For this reason, generalized inferences should not be

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[3] Study conducted in cooperation with the SMC.

Table 1—Source, naming, average age, and sample size of trees used to make up the analytical groups compared in this analysis

Source of trees and analytical group[a]	Treatment or age class (years)	Mean stump age	Number of trees
		Years	
Port Blakely:			
95-UT	XT-1 (UT)	91	25
95-TH	XT-1 (TH)	93	25
80-UT	XT-7 (UT)	72	25
80-TH	XT-7 (TH)	73	25
Stand Management Cooperative:			
21-40	21-40	32	124
41-60	41-60	49	113
61-80	61-80	64	41
81-100	81-100	86	11

[a] UT = untinned; TH = thinned.

made from analyses presented here. The analyses do, however, provide a qualitative description of the way wood characteristics change in different-aged trees and how the trees from the Port Blakely installations fit into the continuum of changing quality with age that can be constructed from the trees in the ESP tree quality database (Stevens and Barbour 2000).

Method of Comparison

Data were organized into a set of eight analytical groups, the thinned and unthinned sample from each of the two Port Blakely XT installations and the SMC trees divided into four age classes (table 1). The designations used for the Port Blakely trees are 95-UT, 95-TH, 80-UT, and 80-TH. They refer to the approximate age at which the installation was harvested[4] and type of treatment, thinned (TH) or unthinned (UT). The SMC age classes are designated as 21-40, 41-60, 61-80, and 81-100 to reflect the harvest ages of the trees included in each class.

The treatments at the Port Blakely installations were unreplicated, and the grouping of the SMC trees is by age class rather than by stand. Although artificial, these groupings are thought to represent the population of Douglas-fir managed under similar conditions. The response variables for this analysis were generated either by combining empirical data on the morphological characteristics of logs or by using regression models developed elsewhere to estimate lumber grades. Consequently, comparisons described in this analysis are based on interpretations of tables and graphs of the averages for each group rather than statistical analysis of the variation among the groups.

[4] Based on estimated stand initiation date. Average stump ring counts for the sample trees are shown in table 1.

The Port Blakely trees were compared by installation and treatment. The type of grouping used for the SMC trees was chosen because commercial thinnings tend to fall into the 21- to 40-year age class, second thinnings and clear felling on private land tends to coincide with the 41- to 60-year age class, and one of the Port Blakely installations falls into each of the next 20-year age classes. On national forests and BLM land, the final thinning in late-successional reserves will occur between ages 60 and 80, and harvests from the "matrix" land could fall into any of these classes (USDA and USDI 1994).

Field Data Collection

When the Port Blakely trees were felled and bucked, each log was labeled with a unique number that identified the treatment (TH or UT), tree from which the log came, and position the log came from within the tree. Stump ring counts were taken to determine tree age. Woods length logs were moved to a paved log yard where additional measurements were made including large-end diameter, small-end diameter (SED), and midpoint diameter inside bark, as well as diameter inside bark 4 feet from the large end of each butt log. Large-end, small-end, and juvenile wood diameter for each log were measured according to standard scaling procedure, which uses the average of the smallest cross-sectional diameter and a diameter measured at 90° to the smallest diameter. Midpoint diameter of the Port Blakely logs was measured outside the bark. Bark thickness was measured to the nearest 0.1 inch and subtracted from the diameter outside the bark to obtain diameter inside the bark. Other measurements included bark thickness at each buck point, number of rings on the large and small ends of each log, branch index (BIX) for each mill length log, and juvenile core diameter on the large and small ends of each woods length log. Branch index was calculated as the average of the largest diameter knot in each of the four quadrants (90°s of circumference) of the log surface. The juvenile wood core was estimated as the diameter of the first 20 growth rings from the pith on each end of each woods length log. This method was used to estimate juvenile wood because it is a required input for the Fahey and others (1991) MSR lumber grade yield models.

Port Blakely trees were bucked to preferred woods length logs of 35 feet to an 8-inch top. Stand Management Cooperative trees were bucked into 40-foot woods length logs with a minimum top diameter of 4 inches. Lengths differed because Port Blakely manufactured their logs for export, whereas the SMC trees were processed for the domestic market. Analysis of log grades is based on woods length logs. Analyses of lumber grade yields are based on mill length logs. The Port Blakely logs were sold full length so data for the lumber analysis was taken on "pencil-bucked" mill length logs. This was generally one 20- and one 14-foot log except when a short woods length log was produced because of a falling break, some other defect, or short top logs. Stand Management Cooperative woods length logs were bucked into mill length logs and sawn into lumber (Fahey and others 1991; Barbour and others [see footnote 3]). In both SMC studies, the preferred mill length log was 20 feet, but shorter logs also were produced when woods length logs were not full length or contained a break or defect.

Table 2—Criteria used to estimate log grades[a]

Grading criteria	Log grade			
	Special Mill	No. 2 Sawmill	No. 3 Sawmill	No. 4 Sawmill
Minimum rings per inch outer portion	6 rings per inch	None	None	None
Minimum scaling diameter	16 inches	12 inches	6 inches	5 inches
Maximum branch diameter	1.5 inches	2.5 inches	3 inches	None
Minimum length	17 feet	12 feet	12 feet	12 feet

[a] These criteria follow the Northwest Log Rules Advisory Group (1998) rules except for the branch frequency requirements for Special Mill and net scale requirements for all grades. Failure to include the net scale requirement is most important for No. 4 Sawmill logs because in practice, larger logs with high defect levels are placed in this grade. In this analysis, only small logs or those with large branches were graded as No. 4 Sawmill.

Estimated Log Grades

Log grades were not recorded in the field, but estimated grades were developed for each woods length log. Methods for log grade assignment basically follow those developed by Christensen (1997) for estimating log grade in standing trees. Christensen's (1997) methods are similar to those pioneered by Gaines (1962) and refined by Lane and Woodfin (1977), except that Christensen (1997) includes actual measurement of branch size in the lower portion of the stem and growth rate at breast height. Differences in the methods used in this analysis included direct measurement of branch size and growth rate for all logs because the trees were felled, which made log ends and branch stubs accessible. Estimated grades were based on the small-end diameter, branch size, growth rate in the outer portion of the log, and minimum length (table 2).

Growth rate in the outer portion of the log was estimated for both Port Blakely and SMC woods length logs by subtracting the radius of the juvenile core (first 20 rings from the pith) from the total radius and dividing the result by the number of rings in the mature wood portion of the log (equation 1). This was done for both ends of the log and averaged. Although this is not exactly how growth rate is defined in the log grading rules (Northwest Log Rules Advisory Group 1998), it is sufficient to obtain an adequate estimate of the growth rate (GR),

$$GR = \frac{\textit{Total ring count} - 20}{r_m}, \tag{1}$$

where

Total ring count is the number of rings in the large or small end of the mill length log,
20 is the number of rings in the juvenile core, and
r_m is the radius of the mature wood portion of the log calculated as the radius of the log minus the radius of the juvenile core.

The maximum branch diameter was taken as the largest of the four measurements made on each woods length log segment for calculating BIX. The Special Mill grade has an additional branch frequency requirement (Northwest Log Rules Advisory Group 1998, p.11). This feature could not be included in this analysis because no branch frequency data were collected. We may therefore have overestimated the number of Special Mill logs.

An SAS program (SAS 1995) was written to sort and grade logs. There was insufficient information to grade either peelers or No.1 Sawmill logs. The protocol was to first sort logs by diameter (those 16 inches and greater for Special Mill) then by knot size. Those that met both the diameter and knot size restrictions for Special Mill were then tested to ensure that growth rate was less than six rings per inch and that logs met the appropriate length requirement. Logs failing to meet requirements for Special Mill were tested as No. 2 Sawmill logs and so on (table 2).

No adjustment in log grade was made for net scale because the logs from the Port Blakely trees were not scaled. Field observations revealed little defect or deformation in these logs, but because the defects were not recorded, they could not be included in the log grading protocol. The methods used to assign grade restricted the No. 4 Sawmill grade to logs with an SED of less than 6 inches. In reality, larger defective logs, with low net scale volumes, also are placed in this grade. This illustrates a shortcoming in the analysis because some defective larger logs could in theory have been graded as other than No. 4 Sawmill. On the other hand, even the oldest stands in this study are relatively young in terms of the biological capability of Douglas-fir. Stands in this age range typically would not display high levels of defect. The PNW Research Station over the past 30 years has analyzed many logs from several Douglas-fir wood product recovery studies to evaluate the importance of the net scale requirement. This evaluation was accomplished by using the database described by Stevens and Barbour (2000). The results suggest that the average defect in trees younger than 100 years old is always less than 5 percent of the gross scale volume and usually much less than that. So we feel that the grading system used here adequately represents log grade for the purposes of this analysis.

Estimates of Lumber Grade Yields

Estimates of visual and MSR lumber grade yields for each mill length log (8 to 20 feet) from both the Port Blakely and the SMC trees were made by using grade recovery models developed by Fahey and others (1991). These estimates are based on the BIX for visual grades and BIX and juvenile wood percentage for MSR grades.

Selection of lumber grades—The visual lumber grades reported in this analysis are those included in the structural joists and planks for 6-inch and wider lumber or Structural Light Framing grades for 4-inch wide lumber (WWPA 1991). The MSR lumber grades are 2100 fb, 1650 fb, 1450 fb, Utility (or No. 3 depending on the width of the lumber), and Economy (WWPA 1991). This set of grades is not the same one that a mill would choose when processing Douglas-fir. Mill managers typically select a mix of grades that maximizes their value recovery. The optimization process includes information about current markets, orders, and the technical capability of the mill. The grade recovery models in Fahey and others (1991) attempt to generalize a set of grades useful for describing the characteristics of a resource.

In practice, mills that visually grade lumber under the Structural Light Framing or the Joists and Planks rules also use other visual rules to increase value. Sometimes various laminating grades are sorted to capture the increased value of higher quality lumber. In other cases, grading rules are mixed to minimize production of low-value grades. For example, 2 by 4 lumber that would be downgraded to No. 3 and sold for as little as $180 per thousand board feet[5] under the Structural Light Framing rules often qualifies as Standard under the Light Framing Rules (WWPA 1991) and can be sold for $335 per mbf. This ability to mix grading systems could make a considerable difference in the profitability of a mill.

The situation for MSR lumber is somewhat different. Fahey and others (1991) chose to represent MSR lumber as a set of three MSR grades and two visual grades. In reality, mills produce a much more complex mix of grades. Grading rules allow visual restricted grading options for lumber that fails to make the lowest MSR grade manufactured by a mill. The rules require placing this lumber in visual grades with mechanical properties below the lowest MSR grade the mill produces. The 1450 fb grade estimated by the Fahey and others (1991) model has design values rated lower than any Douglas-fir visual grade except Utility. If a Douglas-fir mill actually produced the 1450 fb grade, it would preclude manufacture of all other visual grades except Utility and Economy. For the same reasons given in the example for No. 3 mentioned earlier, it is unlikely Douglas-fir mills actually would produce the mix of MSR grades reported in this analysis. This grade mix does, however, provide a good profile of the distribution of properties within the resource.

Results and Discussion

The data used to discuss quality at the log level are presented in three tables. Table 3 contains information on the proportion of log volume in each grade for each analytical group. Table 4 includes data about the relative importance of morphological characteristics (diameter, knot size, and growth rate) and processing decisions (length) in determining log grade. These data also are used to demonstrate how some log or stumpage purchasers may benefit by going beyond log grade when making processing decisions. Table 5 summarizes details on the relative importance of each grade-determining characteristic.

Log Grades

Port Blakely thinning trials—All four Port Blakely analytical groups produced good quality logs. Special Mill and No. 2 Sawmill were the two predominant log grades on all four areas. The Port Blakely installations yielded almost no No. 4 Sawmill logs because the utilization standards set by the company (8-inch minimum SED) effectively precluded their manufacture under the grading protocol used in this analysis. A small volume of No. 4 Sawmill logs was manufactured from the 95-UT trees, but otherwise the lowest grade was No. 3 Sawmill (table 3).

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[5] Based on prices reported by Anderson (2000) from September 2000.

Table 3—The proportion of total log volume in each analytical group meeting various log grades displayed by analytical group

Analytical group[a]	Log grade: Special Mill	No. 2 Sawmill	No. 3 Sawmill	No 4 Sawmill	Age	Stand average[b] quadratic mean diameter
	Proportion				*Years*	*Inches*
95-UT	.41	.45	.13	.01	91	24.9
80-UT	.41	.44	.15	.00	72	22.6
95-TH	.56	.36	.08	.00	93	26.9
80-TH	.40	.54	.06	.00	73	29.3
21-40	.00	.20	.74	.06	32	14.5
41-60	.04	.38	.53	.05	49	19.7
61-80	.03	.48	.48	.00	64	16.7
81-100	.37	.38	.19	.06	86	22.4

[a] UT = unthinned; TH = thinned.
[b] Quadratic mean diameter at breast height of sample trees.

Table 4—Reason why logs were not placed in the next higher log grade by analytical group and log grade

Analytical group[a]	Log grade	Grading criteria: Diameter	Knots	Growth rate	Length[b]	Total logs	Total grading criteria exceeded	Average grading criteria exceeded per log
		Numbers[c]						
95-UT	No. 2 Sawmill	25	17	0	0	36	42	1.17
80-UT	No. 2 Sawmill	29	17	4	0	39	50	1.28
95-TH	No. 2 Sawmill	29	22	1	2	38	54	1.42
80-TH	No. 2 Sawmill	22	36	31	1	50	90	1.80
21-40	No. 2 Sawmill	14	8	13	1	14	36	2.57
41-60	No. 2 Sawmill	39	45	24	0	55	108	1.96
61-80	No. 2 Sawmill	20	7	1	1	23	29	1.26
81-100	No. 2 Sawmill	9	3	0	0	10	12	1.20
95-UT	No. 3 Sawmill	24	0	0	0	24	24	1.00
80-UT	No. 3 Sawmill	31	0	0	0	31	31	1.00
95-TH	No. 3 Sawmill	17	0	0	0	17	17	1.00
80-TH	No. 3 Sawmill	14	0	0	0	14	14	1.00
21-40	No. 3 Sawmill	137	8	0	0	138	145	1.05
41-60	No. 3 Sawmill	151	23	0	0	156	174	1.12
61-80	No. 3 Sawmill	58	1	0	0	58	59	1.02
81-100	No. 3 Sawmill	10	1	0	0	10	11	1.10
95-UT	No. 4 Sawmill	0	1	0	0	1	1	1.00
80-UT	No. 4 Sawmill	0	0	0	0	0	0	0
95-TH	No. 4 Sawmill	0	0	0	0	0	0	0
80-TH	No. 4 Sawmill	0	0	0	0	0	0	0
21-40	No. 4 Sawmill	22	2	0	0	23	24	1.04
41-60	No. 4 Sawmill	12	4	0	0	16	16	1.00
61-80	No. 4 Sawmill	0	0	0	0	0	0	0
81-100	No. 4 Sawmill	1	1	0	0	1	2	2.00

[a] UT = unthinned; TH = thinned.
[b] Length depends on merchandising decisions by individual companys.
[c] Entries represent number of times this grading criteria was exceeded.

Table 5—Proportion of logs downgraded from Special Mill to No. 2 Sawmill or No. 3 Sawmill by analytical group[a]

Analytical group	Log grade	Grading criteria: Diameter	Knots	Growth rate	Length
95-UT	No. 2 Sawmill	0.69	0.47	0.00	0.00
80-UT	No. 2 Sawmill	.74	.44	.10	.00
95-TH	No. 2 Sawmill	.76	.58	.03	.05
80-TH	No. 2 Sawmill	.44	.72	.62	.02
21-40	No. 2 Sawmill	1.00	.57	.93	.07
41-60	No. 2 Sawmill	.71	.82	.44	.00
61-80	No. 2 Sawmill	.87	.30	.04	.04
81-100	No. 2 Sawmill	.90	.30	.00	.00
95-UT	No. 3 Sawmill	1.00	.00	.00	.00
80-UT	No. 3 Sawmill	1.00	.00	.00	.00
95-TH	No. 3 Sawmill	1.00	.00	.00	.00
80-TH	No. 3 Sawmill	1.00	.00	.00	.00
21-40	No. 3 Sawmill	.99	.06	.00	.00
41-60	No. 3 Sawmill	.97	.15	.00	.00
61-80	No. 3 Sawmill	1.00	.02	.00	.00
81-100	No. 3 Sawmill	1.00	.10	.00	.00

[a] Proportions sum to greater than 1.0 because some logs exceed more than one grade determining criteria.

Both thinned areas had a somewhat better log grade distribution (more Special Mill and No. 2 Sawmill volume) than the corresponding unthinned areas. About 85 percent of the volume from both unthinned areas was in Special Mill and No. 2 Sawmill grade logs, whereas the thinned areas yielded 94 percent (95-TH) and 92 percent (80-TH) in these grades. Although no precise records are available, the strategy was to thin from below and attempt to remove mortality and defective trees (Curtis 1995). This practice presumably improved log grade in the residual stand, thereby eliminating the trees that would later yield low-grade logs. Stinson (1999) reports data for the volume removed from the XT-1 (95-TH here) installation during the various entries but not the quality of this material.

The log grade distributions in the two unthinned areas were virtually identical, but the log grade distributions in the thinned areas differed from one another, thereby suggesting that the intensity of the thinning and possibly harvest age may have affected log grade distribution. The Port Blakely 95-TH trees were older at harvest and received a lighter thinning treatment than the trees on the 80-TH area. Both of these factors are consistent with the observed log grade yield results. Proportional volume of Special Mill grade logs was about one-third higher for the 95-TH analytical group than any of the three other Port Blakely analytical groups (fig. 1). Although it is not possible to use the available information to say conclusively why these differences occurred, sufficient information exists to rule out some possibilities and highlight others. The most likely explanations for these types of differences are (1) tree size, (2) spacing at stand initiation, (3) timing of thinning, (4) thinning intensity, and (5) age at harvest. Of these, thinning intensity seemed the most likely cause for the differences in log grade observed for the Port Blakely trees.

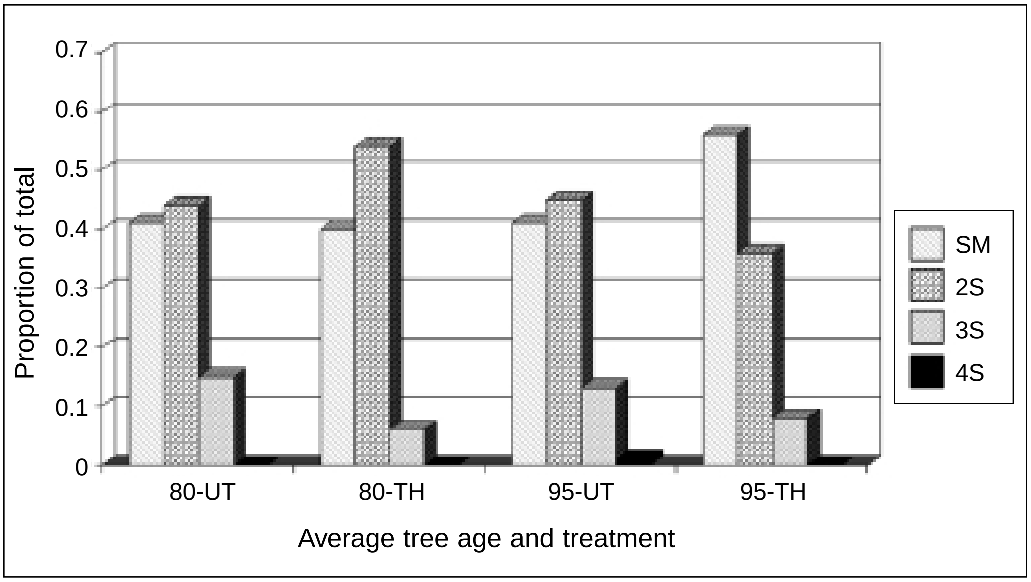

Figure 1—Proportion of total woods length log volume in each log grade from each Port Blakely analytical group (UT = unthinned; TH = thinned). SM = Special Mill, 2S = No. 2 Sawmill, 3S = No. 3 Sawmill, and 4S = No. 4 Sawmill.

Tree size is not the reason. The 80-TH trees were larger yet yielded a lower proportion of volume in Special Mill (table 3), the most diameter-sensitive grade (table 2). The stands also were thinned at about the same age, so it is unlikely that age at thinning led to the observed difference in grade yield.

Spacing at stand initiation is important because it is one of the major factors determining branch size (Larson 1969). Little information is available about the conditions in these stands at the time they were established, but Curtis (1995) concluded that both Port Blakely installations were probably initially widely spaced. Curtis bases this conclusion on the number of trees present when the stands were first thinned as well as evidence of mortality before thinning. Although it is unknown if the stocking in one stand was heavier than in the other, the closeness of proportional grade yields for the unthinned areas supports the idea that the stocking levels were similar and that the thinning treatment, not initial conditions, created the differences between installations. Curtis also rates both sites as II+ so differences in site quality were probably not a factor.

Thinning intensity may have influenced log grade yield. The 95-TH area was thinned frequently but lightly at 47, 55, 60, 74, and 77 years old. The 80-TH area was thinned heavily at ages 42 and 54 then lightly at age 62. The relative density of the 80-TH area had not recovered to a point where suppression-related mortality was anticipated by the time it was remeasured at age 76 (Curtis 1995). Data presented in table 4 show that growth rate and knot size were much more important in limiting log grade for the logs from the 80-TH analytical group than for those from any of the other Port Blakely analytical groups. This is consistent with expectations for stands maintained in relatively open conditions.

The differences in treatment appear to have promoted rapid branch and stem diameter growth in the trees from the 80-TH area but only moderate branch growth and stem diameter growth in the trees from the 95-TH area. Information collected on BIX supports this idea even though it was not possible to reconstruct histories of branch size over time. Change in branch size with tree height provides a surrogate for this information. Lower branches provide a picture of conditions before treatment, whereas the upper branches provide a snapshot of treatment effects. The average BIX for each 17.5-foot log from each Port Blakely analytical group is plotted in figure 2. Although it is not possible to say which logs grew before or after the thinning, it is reasonable to generalize the influence of thinning from the height trends. On both installations, BIX was smaller in the lower logs from the thinned areas than the lower logs from the unthinned areas, thereby suggesting that either these differences existed before thinning or some trees with large branches were removed during thinning. The latter is consistent with the goal of improving both growth and quality of the residual trees by removing small, poorly formed, and branchy trees. Regardless of the cause of this initial difference, the height trend indicates a response to thinning. As log height increased, the BIX on both thinned areas became larger than the BIX on the corresponding unthinned areas. The lighter thinning treatment received by the trees in the 95-TH area seems to have increased stem diameter enough to improve yield of Special Mill logs without increasing either branch size or growth rate enough to disqualify many of those larger logs from the higher grade. In contrast, the heavier thinning received by the trees in the 80-TH area increased both branch diameter and ring width beyond the allowable limits, thereby disqualifying many large logs from the Special Mill grade (table 5).

Trees from the 95-TH area were 15 years older at harvest than those from the 80-TH area, but it is unclear if age was an important factor in the observed differences in log grade yield. Proportional log grade yields from the two unthinned areas were virtually identical (table 3). Trees from the younger 80-TH area were larger (table 3), yet yielded about one-third less of their total volume in Special Mill grade logs than the older 95-TH trees (fig. 1). This happens because growth rate and branch size were more important factors in determining grade in the younger trees than in the older ones (table 4). Extending the rotation without additional thinning could result in slower diameter growth, which in turn might allow more logs to meet the growth rate criteria for Special Mill. The 95-TH trees were also old enough to begin branch stub occlusion after natural pruning (Kachin 1940). Occlusion also might result in reduction in number of knots counted by the scaler during grading because they become less obvious as they are overgrown. Using the methods developed by Christensen (1997) for projecting stand developmental trajectories might help to evaluate the importance of these potential changes and answer questions about how the characteristics of the 80-TH trees might change were they grown for another 15 years.

Stand Management Cooperative trees—Age does, however, seem to explain much of the change in proportional log grade when the full 20- to 100-year age range is examined. The proportion of No. 3 Sawmill log volume declined with age, whereas the proportion of volume in No. 2 Sawmill and Special Mill logs increased over this age range (fig. 3). An exception to this trend was seen in the age class 41 to 60 years and 61 to 80 years where there was a slight decline in the proportional volume of Special

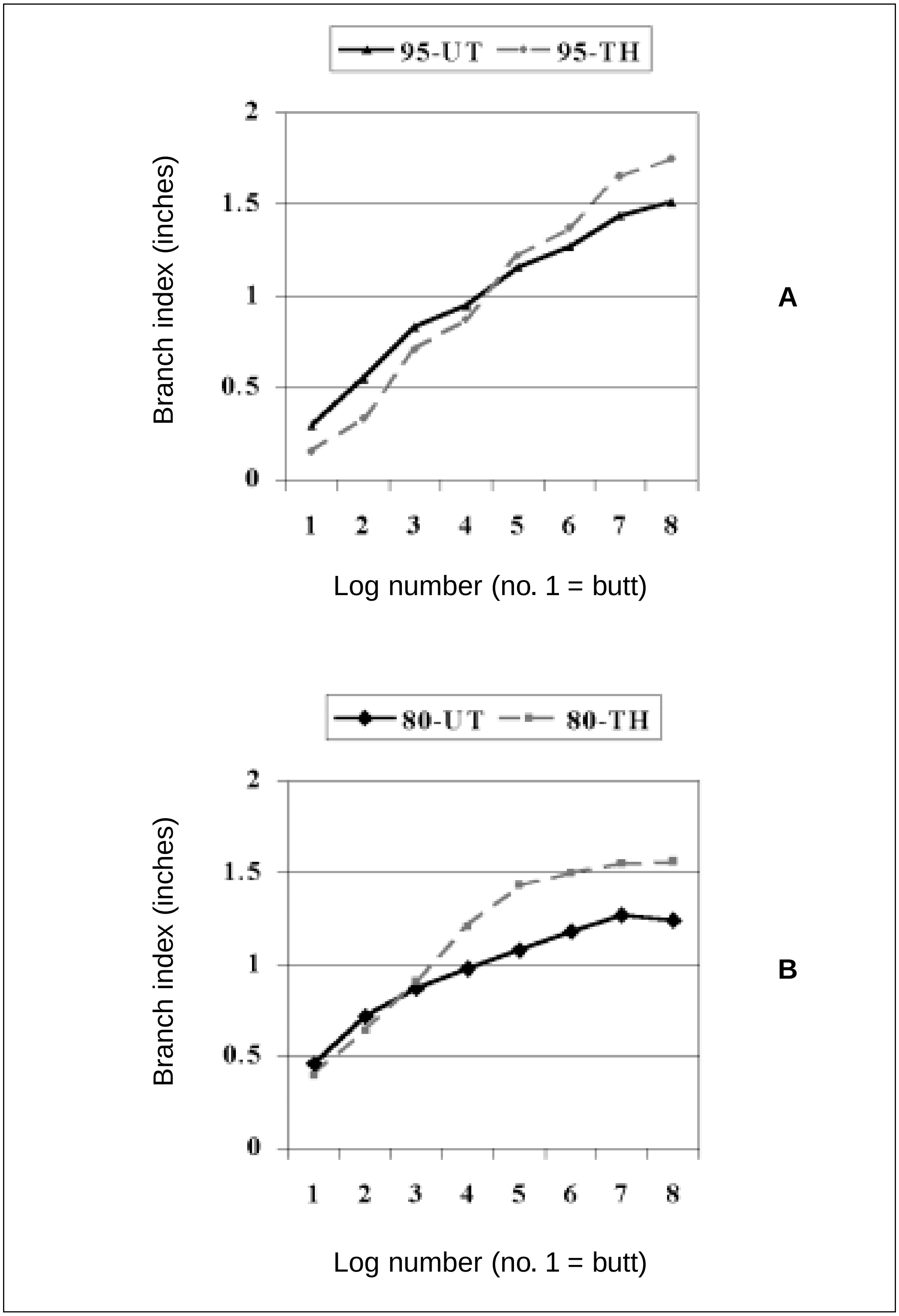

Figure 2— Change in branch index (BIX) with mill length log height (17.5 feet per log) for the trees from each Port Blakely analytical group.

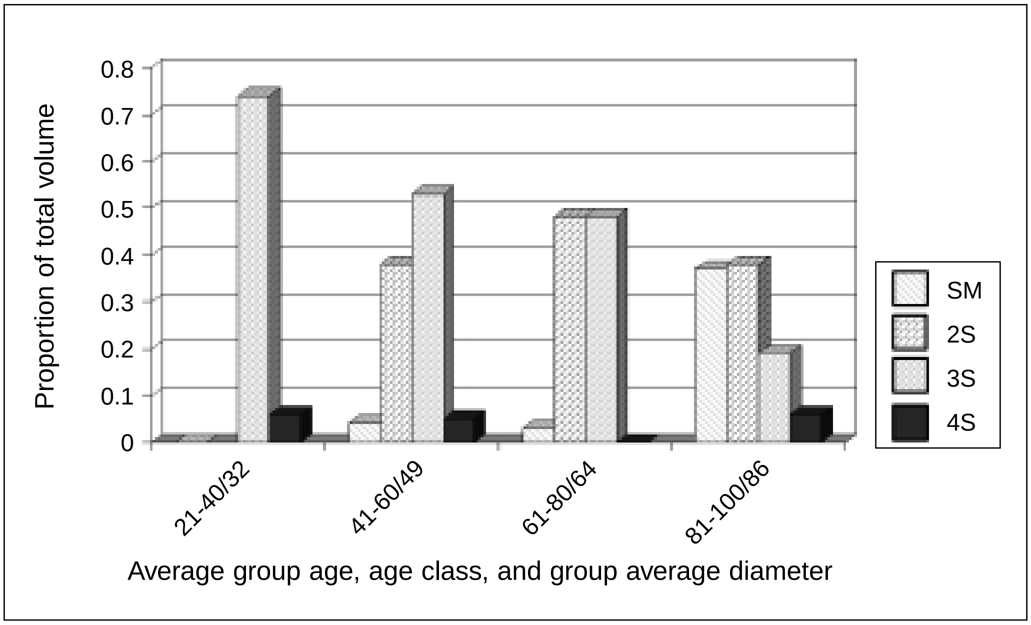

Figure 3—Proportion of total woods length log volume in each log grade for analytical groups of SMC trees arranged by age class (x-axis label also shows average age and quadratic mean diameter for the tree in each group). SM = Special Mill, 2S = No. 2 Sawmill, 3S = No. 3 Sawmill, and 4S = No. 4 Sawmill.

Mill logs (table 3). This is apparently linked to the diameter of the two groups (proportion of logs downgraded to No. 2 sawmill for diameter, table 5). The trees from the 41- to 60-year age class had a quadratic mean breast height diameter (QMD) of 19.7 inches. The trees from the 61- to 80-year age class had a smaller QMD of only 16.7 inches. The Special Mill grade requires a minimum SED of 16 inches, so in at least half of the trees in the 61- to 80-year age class, a 34-foot butt log was unlikely to yield a Special Mill log. This decline in the proportion of Special Mill logs occurred even though the younger 41- to 60-year age class trees had an average BIX that was nearly one and one-half times as large as the 61- to 80-year age class trees (1.41 inches vs. 0.97 inch). Thus, the No. 2 Sawmill logs produced from the younger 41- to 60-year age class trees would be noticeably “rougher” than those from the 61- to 80-year age class (table 4). This is evident from the higher number of grading criteria exceeded per log. Although it is impossible to completely separate diameter from age in this analysis, diameter was always an important factor in determining log grade in all analytical groups. All but 33 of the 362 logs from the SMC database graded as No. 3 Sawmill, and all those from the Port Blakely thinning trials placed in that grade were downgraded only for diameter (table 4).

Relative Importance of Log Grading Criteria

Table 4 contains information about the reasons logs failed to qualify for the next highest log grade. Even though two groups of logs may be assigned to the same grade, their “quality” can be quite different. The latitude in quality allowed within a single grade is apparent when the number of grading criteria exceeded per log is compared among all analytical groups for the No. 2 Sawmill grade (table 4, final column in rows 1-8).

The logs from trees in the younger two SMC age classes exceeded more grading criteria than either those from the older SMC age classes or the Port Blakely trees. The 95-UT No. 2 Sawmill logs (row one, last column in table 4) exceeded an average of 1.17 grading criteria per log, and those from SMC age class 21-40 exceeded an average of 2.57 grading criteria per log (row 5, table 4). This means that for the 95-UT trees, about 17 percent of the No. 2 Sawmill logs contained features that exceeded at least two grading criteria. The other 83 percent of the No. 2 Sawmill logs only exceeded one grading criterion. The No. 2 Sawmill logs from the SMC age class 21-40 typically exceeded two grading criteria, but 57 percent of them exceeded three. All of these logs were nonetheless assigned to the No. 2 Sawmill grade under existing rules (Northwest Log Rules Advisory Group 1998). This means that at least the appearance of the logs from the two groups would be noticeably different. Some differences in the types of products manufactured from them also might be expected, and in fact, the market currently recognizes the range of quality within some log grades because different prices are reported for old- and young-growth Special Mill, No. 2, and No. 3 Sawmill grades (Log Lines 1999).

More subtle but possibly important differences also are seen among the Port Blakely analytical groups. For example, the data presented in table 3 suggest that, based on log grade alone, the trees from thinned areas have higher quality than those from unthinned areas. When the data are reexamined by using the techniques presented in table 4, a different, more complex picture develops. Although the trees from thinned stands produce larger proportional volumes in the higher grades, the No. 2 Sawmill logs from the thinned stands exceed more grading criteria per log than those from the unthinned stands. This suggests that at least by some measures, the logs within the No. 2 Sawmill grade from the unthinned stands are of higher quality. This result is consistent with more general information on branch size and quality seen after thinning reported for both Douglas-fir (Maguire and others 1991, Riou-Nivert 1989) and other species (Alazard 1994, Barbour and others 1994, Colin and others 1992). Consequently, more demanding log grading systems, such as those used for proprietary export grades, might reveal greater differences between trees from the thinned and unthinned area, than are apparent here.

Comparison of Port Blakely trees and SMC database trees—The proportion of logs that exceeded each grading criterion for each analytical group is shown in table 5. This representation of the data shows the influence of the heavy thinning received by the 80-TH trees on the criteria used to evaluate log grade. The 80-TH analytical group is the only Port Blakely analytical group where growth rate was an important factor in disqualifying logs from the Special Mill grade. Knot size was also more important for this group than for the other three Port Blakely analytical groups. Based on the data in table 5, the No. 2 Sawmill logs from the 80-TH trees are most similar to those from the SMC 41- to 60 year age class. Or, in other words, No. 2 Sawmill logs from this 80-year-old stand might closely resemble those from stands one half to two-thirds that age. It is important to keep in mind, however, that although the logs graded as No. 2 Sawmill from these two groups had similar characteristics, 40 percent of the volume from the 80-TH group qualified as Special Mill, but only 4 percent of the volume from the age class 41- to 60 year SMC trees made that grade (table 3).

Table 6—Average volume percentage of yields of visually graded lumber by grade from each analytical group[a]

Analytical group	Select Structural	No. 1	No. 2	Utility or No. 3	Economy	No. 2 and Better.	Branch index
	Lumber grade						
	Percent						*Inches*
95-UT	21	20	46	10	4	86	0.89
80-UT	17	21	46	11	5	84	.90
95-TH	25	17	45	10	4	87	.87
80-TH	17	19	48	12	5	83	1.05
21-40	5	15	53	19	8	73	1.32
41-60	5	12	51	22	11	67	1.41
61-80	16	20	47	12	5	83	.97
81-100	25	21	43	9	4	88	.88

[a] Lumber grade yields were estimated by using grade prediction models developed by Fahey and others (1991) for WWPA Structural Light Framing and Joists and Planks grade rules (WWPA 1991).

Table 7—Average volume percentage of yields of machine stress rated (MSR) lumber grades for each analytical group[a]

Analytical group	2100fb	1650fb	1450fb	Utility or No. 3	Economy	Juvenile wood
	Lumber grade					
	Percent					
95-UT	25.0	37.2	18.0	13.4	6.3	28.2
80-UT	23.3	36.9	18.2	14.9	6.6	35.0
95-TH	24.9	36.5	20.0	12.3	6.3	24.1
80-TH	22.5	35.7	18.3	16.0	7.4	24.8
21-40	9.1	26.0	24.1	29.4	10.7	83.3
41-60	8.6	23.5	21.6	29.1	17.2	57.5
61-80	22.0	37.3	16.3	15.9	8.5	39.0
81-100	28.8	40.7	13.2	10.5	6.8	33.8

[a] Grades were estimated by using equations developed by Fahey and others (1991) for MSR lumber. The "grades" are approximations based on edge knot size and stiffness.

Lumber Yields

Estimated yields of visually graded and MSR lumber for the trees from the Port Blakely thinning trials and the SMC trees are presented in tables 6 and 7. These are composite results for all logs from all trees in each analytical group. Lumber grade yields are reported as a percentage of the total board-foot lumber tally for each analytical group. Lumber tally is dependent on log diameter and was estimated by using the lumber recovery factor model of Fahey and others (1991).

The average BIX for each analytical group is included in table 6 because the visual lumber grade yield models developed by Fahey and others (1991) use BIX as their only independent variable. These relations are independent of log diameter. Branch index varied in the narrow range between 0.89 and 1.05 inches for all the analytical groups except the SMC age classes 21 to 40 years and 41 to 60 years, which had much larger branches (BIX 1.32 and 1.41 inches). As mentioned earlier, these trees probably grew in stands that were either established at wider spacings or respaced earlier than either the older SMC stands or the Port Blakely thinning trials.

The recovery models for MSR lumber include both BIX and percentage of juvenile wood as independent variables (Fahey and others 1991) and so percentage of juvenile wood is included in table 7. The MSR grade yield models have a slight dependence on diameter because the juvenile wood diameter is fixed once trees reach 20 years old at a given height. As total diameter increases, the proportion of juvenile wood slowly declines, and MSR grade yield improves.

Port Blakely trees—The results for visual lumber grade yield were consistent with the log grade results already presented. Estimates of visual lumber grade yield for the trees from all the Port Blakely thinning trials were similar regardless of whether the area was thinned, although the older (95-TH and 95-UT) trees had slightly higher yields of Select Structural lumber. The results for MSR lumber agreed with those for visually graded lumber (table 7). The similarity between trees from the thinned and unthinned areas indicates that when middle-aged stands are thinned, there is little influence on quality if structural lumber is the intended product. This result is consistent with Christensen’s (1997) findings for the Hoskins level-of-growing-stock installation. The Port Blakely thinning trials were thinned when stands were 40 years old or older and, by this time, the branches in the lower portions of the stems, where the greatest volume is concentrated, were almost certainly dead. Branch size was therefore fixed so faster growth after thinning would not necessarily substantially alter lumber grade distributions.

Stand Management Cooperative trees—The results for visually graded and MSR lumber for the SMC database trees are different than those for the Port Blakely thinning trials (tables 6 and 7). The distribution of both visual and MSR grades indicates a considerable change in quality in the trees that are older than 60 years as compared to those younger than 60 years. At this level of analysis, it is not clear if these results reflect some quirk in the data or if these differences actually represent differences in quality related to changing silvicultural practices over the past 40 years. Initial spacing or precommercial thinning seems to have influenced the characteristics of the SMC database trees where the younger trees have considerably larger branches (table 6) and higher percentage of juvenile wood (table 7). The observed increases in branch size and proportion of juvenile wood are consistent with results reported in the literature for widely spaced and early thinned Douglas-fir and other species (Barbour and others 1997, Briggs and Smith 1986). It therefore seems likely that the information in tables 6 and 7 actually reflects differences in young stand management. This is not surprising because the SMC trees were intentionally selected to represent trees grown by using silvicultural practices designed to favor rapid wood production.

If this assumption is correct, these data indicate that the practices used to grow the younger trees have put them on a trajectory for lower quality that will influence their characteristics and consequently their market value under any economically viable rotation. Even if the trees from the SMC age classes 21 to 40 and 41 to 60 years were grown until they reached age 80, they still would have large branches in their lower boles as well as higher in the stem if rapid growth is maintained during the entire rotation. The BIX reported for these trees in table 6 is fixed and will not decline with age. The relation between growth rate and the proportion of juvenile wood is complex because at any height, the volume of juvenile wood is fixed once trees make the transition to mature wood production. The longer the trees grow, therefore, the less juvenile wood they will contain as a proportion of their total volume. Given two trees of equal size, the one that grew more slowly when young will tend to have a lower proportion of juvenile wood than the one that grew more quickly when young. Although the proportion of juvenile wood will slowly decline with increased diameter, large branches will still negatively influence MSR lumber grade yields. The important point is that simply growing the younger trees longer would not lead to the same product yields as are seen in the trees from the Port Blakely thinning trials or the two older age classes of SMC trees.

Conclusions

Management history seemed to influence the characteristics of the trees examined here. Analysis of the SMC trees by age class reveals a gradual increase in log and lumber grades with increasing stand age. The Port Blakely trees fit into this continuum fairly well. Log grade, visual lumber grade, and MSR lumber grade results suggest that Douglas-fir wood quality increases fairly rapidly until about stand age 60 and then apparently levels off. The trees from the five oldest analytical groups had similar log and lumber grade yields although the SMC trees in this age class came from the central Cascade Range in Oregon, and the Port Blakely thinning trials were on the Olympic Peninsula in western Washington. The evaluation of lumber grades performed in this analysis did not, however, recognize increasing clear wood volume because only structural lumber was considered in the estimated grade yields. Data available in the literature on natural pruning suggest that quality may begin to increase again at about age 100 when recoverable amounts of clear wood have formed. The log grade results tend to account for this because the Special Mill grade is intended to capture the potential yield of Select and Better lumber. Even so, there was little difference in log grade between the older and younger Port Blakely thinning trial that could be attributed to age.

The differences in quality between trees from thinned and unthinned Port Blakely areas were relatively small. The trees from thinned areas tended to yield larger proportions of higher graded logs than from unthinned areas. For logs of equal grade, however, logs from the unthinned areas tended to have fewer characteristics that prevented them from being placed in the next higher grade than the logs from the thinned areas. So, some processors might consider logs of equal grade from unthinned areas as higher quality than the logs from thinned areas. There were essentially no differences in estimated grade yields of visually graded or MSR structural lumber among the trees from the various analytical groups from the Port Blakely thinning trials. This analysis did not, however, include estimates of grade yields for appearance grade lumber, which might have revealed greater differences in quality between the logs from thinned and unthinned areas.

Diameter was always an important factor in determining if logs were placed in all grades; however, two of the other grading criteria, that is, knot size and growth rate, were as important or more important than diameter in determining if logs met the criteria for the Special Mill grade. Even when young trees are large enough to make Special Mill logs, they rarely do because either their branches are too large or their growth rate is too high. Branch size and growth rate also are related to stand tending; for example, initial spacing and the timing and intensity of thinning, as well as site quality.

A continuum of improving log and lumber grade yield was apparent with tree age, and this was common across analytical groups. For example, the trees from the SMC age class 81 to 100 years yielded similar proportions of logs and lumber in the various grades as did the Port Blakely trees. As the age of the SMC trees declined, branch size and juvenile wood dimensions changed in ways that could not be accounted for simply by tree or stand age, and these changes also influenced log and lumber grade. This probably reflects a shift from more extensive to more intensive forestry practices on industrial land in western Oregon and Washington over the past 50 years, but in most cases, we have insufficient plot level treatment histories to say this conclusively. Practices such as use of genetically improved planting stock, herbicides to reduce vegetative competition in young stands, wide initial spacing, precommercial thinning, and commercial thinning all are consistent with the trend toward the larger branches and wider juvenile wood cores observed in the younger trees. It is, for example, clear from the analyses presented here that trees grown by using the long rotation forestry and relatively late thinnings practiced in Port Blakely's XT-1 and XT-7 thinning trials had different wood characteristics than trees grown by using the high-yield forestry techniques practiced for the two youngest SMC age classes and that those differences would persist even if the SMC trees were grown to the same age as the Port Blakely trees.

The potential importance of site quality, however, should be considered when interpreting the results from this study. All of the trees analyzed here came from either site I or site II land, and yet much of the land owned by the federal government is at higher elevations and lower site classes where slower growth is expected even with earlier and heavier thinnings. This might tend to mitigate branch size, growth rate, and juvenile wood diameter, but it would reduce total diameter, thereby making the effect on log grade yield difficult to predict.

These results do, however, suggest that the longer rotations used under the NWFP "matrix" land specifications could result in trees with different wood characteristics than those grown either in industrial plantations or of older trees grown under past forest management practices. This, of course, depends on the timing and intensity of thinnings used to alter structure in the existing stands. The earlier and heavier the thinnings, the more the trees from longer rotations will resemble trees from plantations managed for rapid growth. If late heavy thinnings like the regime used on the Port Blakely XT-7 installation (80-TH analytical group) are used, large trees with moderate branch size and growth rates should result. The positive effect of diameter will lead to some improvement in the domestic log grade mix from the older stands but little, if any, change in the proportions of various lumber products manufactured from them. On the other hand, late light thinnings, similar to those used by Port Blakely on the XT-1 thinning trials (95-TH analytical group), will result in trees that are somewhat smaller for a given age but with characteristics that might make them more desirable for certain wood products with higher market value. If early, heavy thinnings are used, the negative effect on proportional log and lumber grades probably will be more pronounced than that seen for the two Port Blakely installations. These differences still need to be quantified, but it is apparent from the difference in knot size, juvenile wood proportion, and growth rate between the more intensively managed SMC trees and the Port Blakely trees that longer rotations that result in larger trees will not necessarily result in trees with significantly higher market value for wood removed from these stands.

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