

MECHANICAL GRADING OPPORTUNITIES FOR LUMBER  
SAWN FROM SMALL-DIAMETER LOGS

A Thesis

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Major in Forest Products

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College of Graduate Studies

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by

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## AUTHORIZATION TO SUBMIT THESIS

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## ABSTRACT

Sawmills of the Inland Northwest are faced with dwindling supplies of high-quality logs that are being replaced with smaller-diameter logs. Current forest management practices aimed at ecosystem restoration and improving forest health are two of the causes of the shift in log quality. One method to offset the loss of log value at mills may be to produce Machine Stress-Rated (MSR) lumber instead of visually graded lumber. However, the mechanical properties of lumber from small-diameter logs must be determined before lumber manufacturers invest in the equipment required to produce MSR lumber. The purpose of this study was to determine the mechanical properties and corresponding economic value of a group of lumber produced from forest stands that are typical of those being harvested to improve forest health and restore the ecosystem.

Ponderosa pine logs for this study were obtained from a plantation stand, and lodgepole pine and grand fir logs were obtained from a stagnated, over-populated second growth forest. Both harvest sites were located in northern Idaho. The logs were primarily manufactured into 12-foot 2x4's, and the lumber was visually graded and tested for modulus of elasticity and modulus of rupture. Further analysis was not performed on the ponderosa pine sample group because it had low strength properties. The grand fir and lodgepole pine were sorted into two types of grade categories: visual Structural Light Framing and Machine Stress-Rated Lumber. These two species had good visual and mechanical characteristics. Machine stress-rating the lodgepole pine group produced a \$27/Mbf increase in value above visual grading. Machine stress-rating the grand fir group produced a \$15/Mbf increase in value above visual grading.

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**TABLE OF CONTENTS**

Title page .....	i
Authorization to submit thesis .....	ii
Abstract.....	iii
Vita.....	iv
Acknowledgments.....	v
Table of Contents.....	vi
List of Tables .....	vii
List of Figures.....	viii
Introduction.....	1
Methods.....	4
Results and Discussion .....	9
Conclusions.....	19
Literature Cited.....	20
Appendix A - Grand Fir.....	22
Appendix B - Lodgepole Pine.....	36
Appendix C - Ponderosa Pine.....	47
Appendix D - Formulas .....	58

**LIST OF TABLES**

1. Log size summary. ....	9
2. Gross lumber tally before planing, trimming, and grading. ....	10
3. Lumber yield for visual grades. ....	12
4. Mechanical properties for visual and MSR grades. ....	15
5. Value increase for machine stress-rating. ....	18

**LIST OF FIGURES**

1. Stress vs. deflection plot for typical 2x4's. ....	13
2. Yield comparison for visual and machine grading. ....	16
3. Static modulus of elasticity vs. dynamic modulus of elasticity for grand fir. ....	35
4. Static modulus of elasticity vs. dynamic modulus of elasticity for lodgepole pine. ....	46
5. Static modulus of elasticity vs. dynamic modulus of elasticity for ponderosa pine. ....	57



## INTRODUCTION

The Inland Northwest has many forest stands consisting of dense, predominately small-diameter, same-age trees. Public land management practices of the past decades have created forests with a higher density of small-diameter trees. Many of these stands originated after historical stand replacement fires, where natural regeneration was abundant and self-thinning was minimal. A survey of the Colville National Forest (14) provides a good example of the types of forests which are typical of those that would benefit from thinning. The stands that were studied are characterized by high densities of trees less than 9 inches diameter at breast height (DBH). The species mix consists of lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*) and Douglas fir (*Pseudotsuga menziesii*), often with a thick understory of grand fir (*Abies grandis*).

Thinning of timber stands can increase the quality of future harvests and improve forest health (6). However, thinning these stands produces mostly small-diameter (4-10 in. DBH) logs which do not have a high economic value, and may actually have negative value at the mill (12). Traditionally, the logs from such thinnings have not been utilized for solid sawn lumber because of their low value. These logs have small volume, a high proportion of low density juvenile wood, and a high cost of removal. However, as the average size of logs being harvested has declined, technology has been developed to process small-diameter logs more efficiently, and alternative mill strategies such as producing mechanically graded lumber may increase mill profits (10).

Softwood lumber from western North America is typically graded according to the visual grading rules of the Western Wood Products Association (WWPA) (13). The actual strength of any visually graded piece of lumber can vary significantly from another piece of the same species and appearance, and this variance must be accounted for in structural applications. To allow for this variance, a piece of lumber is given an allowable design strength rating that is usually significantly less than its actual strength. For example, a lodgepole pine 2 x 4 grade stamped as “No.2 Structural Light Framing” has a design bending stress of 1125 psi, but its actual strength is probably greater than 4000 psi (8).

Mechanically graded lumber, also known as Machine Stress-Rated (MSR) lumber, is physically tested by a machine to more accurately estimate its mechanical properties including stiffness and bending strength. MSR lumber is distinguished from visually graded lumber in that each piece is nondestructively tested and marked to indicate its strength and stiffness. MSR lumber benefits the user by assuring that the strength value of any board is more precisely defined. This is of particular importance in engineered structural components such as laminated beams, trusses, and fabricated joists where MSR lumber is typically used.

MSR lumber currently constitutes a small portion of the dimension lumber market, but it may have the greatest potential for growth of sawmill products (7). If the advantages of machine graded lumber can be demonstrated to potential buyers, there will be significant increased demand for MSR lumber.

The production of MSR lumber from smaller diameter logs may offer a higher value alternative to the production of visually graded lumber. However, before lumber manufacturers will invest in high-cost equipment necessary for the production of MSR lumber, the mechanical properties of lumber from logs that are typical of those now being harvested from timber-stand thinnings must be determined. Grand fir, lodgepole pine, and ponderosa pine were identified as the species which are most likely to be produced from timber-stand thinnings and have the most potential for increased income from production of MSR lumber.

The first objective of this study was to determine the visual grade and mechanical properties of a finite quantity of boards sawn from a given volume of small-diameter grand fir, lodgepole pine, and ponderosa pine logs. The second objective was to compare the yield and value for the lumber when graded visually and when machine stress-rated.

## METHODS

Grand fir and lodgepole pine logs were harvested from a second growth, same age forest stand located in the Priest Lake District of the Idaho Panhandle National Forest, approximately 15 miles north of Priest River, Idaho. There is no documented history available, but the district forester was able to provide the following information based on a current inspection (5). The stand was regenerated by a catastrophic fire or a combination of logging and residual burning approximately 45 years ago. The approximate stand species mix is 30% grand fir, 30% lodgepole pine, 20% western red cedar, and 20% western hemlock. The stand has an approximate basal area of 180 square feet per acre, an average height of 65 feet with a range of 47 to 85 feet, and an average DBH of 8 to 9 inches with a range of 7 to 11 inches. Approximately 50 trees of each species were marked for harvest.

The ponderosa pine was harvested from a second growth, five acre site approximately 10 miles southeast of Grangeville, Idaho on the Nez Perce National Forest. The site was planted in 1952, and an inspection in 1965 indicated a population density of 214 trees per acre. By 1974 10 to 12 percent of the trees had dead tops due to porcupine damage. The stand was pruned in 1994. A stocking exam in 1995 revealed a basal area of 90 to 140 square feet per acre, a crown ratio of 40 percent, and an average DBH of 11 to 12 inches with a range of 8 to 16 inches. The site consists of 99 percent ponderosa pine and 1 percent Douglas fir. The logs for this study were obtained by "thinning from below", which removed the poorer quality trees. Approximately 80 trees were harvested (9).

The logs were bucked into 12-foot and 24-foot nominal lengths at the harvest sites and sent to Riley Creek Lumber Co. in Laclede, Idaho for processing. Prior to sawing, the logs were scaled and measured for average maximum knot size. The log ends were color coded to ensure no mixing of species would occur during the manufacturing process.

Sawing of all three species occurred in a single shift dedicated to the manufacture of the lumber required for this study, and no other logs entered the mill during that time. The mill was set up to produce as many 12-foot 2x4's as possible from each log with a secondary priority for 10-foot 2x4's and 8-foot 2x4's. The 12-foot length was chosen because it is a commonly marketed length of MSR lumber. A small quantity of random length 1x4's were also produced as side lumber but were not included in this study. The 2x4 lumber was kiln dried to a moisture content (MC) no greater than 19%, planed to dimension size, and shipped to the University of Idaho, Forest Products Department Laboratory.

All 2x4's (except 8-foot ponderosa pine) were assigned a visual Structural Light Framing grade by a WWPA grader. To improve grade a small quantity of lumber was "pencil trimmed" to a shorter length. The grader also recorded the grade-controlling characteristic for each board. The goal of this study was to evaluate approximately 300 12-foot 2x4's of each of the three species for their potential as MSR lumber. Since this goal was met, 10-foot 2x4's, 8-foot 2x4's and all lengths of Economy grade 2x4's were removed from further study. To assist with MSR grading of the remaining 12-foot 2x4's, the WWPA inspector assigned a visual limitation class per WWPA rules (13).

The dynamic modulus of elasticity (MOE) for each 2x4 was then determined using a Metriguard Model 340 Transverse Vibration E-Computer. The E-Computer determines MOE based on resonant vibration frequency and specific gravity of a given board. The board is placed on two supports to span the length of the board (12 feet for this analysis), and then set into vibration. A load cell measures the frequency of vibration and board weight, and this data is correlated to MOE. A regression equation that correlates static MOE with dynamic MOE for each of the three species was determined to facilitate future field testing of lumber.

An Instron Model 1137 Universal Testing Machine was used to perform the static mechanical strength and stiffness test. Data were collected via a National Instruments model PC-LPM-16 data acquisition board and Measure software. The testing was performed per ASTM Standard D 198 (2). Third point loading was used to create constant moment in the center third of the span. Span length was 73.5 inches to achieve a span-to-depth ratio of 21.

Each piece was loaded at a 2 inch per minute rate of deflection and loading proceeded until ultimate failure. The time to failure averaged approximately one minute. Deflection was measured using an linear voltage differential transducer (LVDT), and force was measured with the load cell on the Instron machine. Force and deflection values were collected at a rate of 3 times per second via the computer data acquisition system. The static MOE was computed by a regression on the force deflection curve in the force range of approximately 200 to 500 pounds with care to avoid using loads beyond the proportional limit.

Immediately after breaking, a small sample (1 inch by 1½ inches by 3½ inches) was removed from each 2x4 to determine moisture content and specific gravity. The moisture content of each sample was determined using the oven-dry method specified by ASTM Standard D 4442 (3). Specific gravity was determined according to ASTM Standard D 2395 (4). In each species group approximately 30 pairs of 48 inch samples were retained and sent to the Forest Products Laboratory for truss plate tests.

The MOE, modulus of rupture (MOR), and visual grade data for each piece was analyzed to sort the lumber into MSR categories. WWP rules allow sorting into any bending strength (Fb) and modulus of elasticity (E) combination (13). However, there are a limited number of categories that are commonly marketed in the Western United States, and for the species considered in this study they include 2400Fb - 2.0E, 2100Fb - 1.8E, 1800Fb - 1.6E, 1650Fb - 1.5E, and 1450Fb - 1.3E (15). For this study we considered only 2400Fb - 2.0E, 2100Fb - 1.8E, and 1650Fb - 1.5E. The MSR categories were compiled according to American Lumber Standard Committee (ALSC) rules (1) which include the following requirements:

- 1) Average MOE for a grade group must be equal or greater than assigned E.
- 2) 95% of the pieces must have MOE greater than 82% of assigned E value.

For 2.0E grade:  $2.0 \times 10^6 \text{ psi} \times 82\% = 1.64 \times 10^6 \text{ psi}$ .

For 1.8E grade:  $1.8 \times 10^6 \text{ psi} \times 82\% = 1.48 \times 10^6 \text{ psi}$

For 1.5E grade:  $1.5 \times 10^6 \text{ psi} \times 82\% = 1.23 \times 10^6 \text{ psi}$

3) 95% of pieces have and MOR greater than 2.1 times the assigned Fb.

For 2400Fb grade:  $2400 \text{ psi} \times 2.1 = 5040 \text{ psi}$

For 2100Fb grade:  $2100 \text{ psi} \times 2.1 = 4410 \text{ psi}$

For 1650Fb grade:  $1650 \text{ psi} \times 2.1 = 3465 \text{ psi}$

ALSC rules also stipulate that after removing MSR boards there shall be no visual grades produced that have a design bending strength greater than the design bending strength of the lowest MSR category produced, which is 1650 psi for this case. When adjusted for size a Select Structural grand fir (Hem-Fir category) 2 x 4 has an adjusted Fb of 2100 psi. Therefore, this is not an acceptable visual grade after 1650 Fb material has been removed. However, the adjusted Fb for a No.1 Hem-Fir is 1425 psi which is less than the lowest MSR category of 1650 psi; therefore, we can produce a No.1 visual grade.

Economic value was determined for each species group. The cost comparison of visual grades versus machine grades was based on approximate current lumber prices as of November 14, 1997.



## Results and Discussion

### Logs

The grand fir and lodgepole pine logs (as measured after bucking to nominal lengths) had an average small-end diameter of 5 to 6 inches. A 456 cubic feet gross volume of grand fir logs was processed in the form of fourteen 12-foot logs and sixty-three 24-foot logs. The lodgepole pine comprised fourteen 12-foot logs and fifty-seven 24-foot logs with a combined gross volume of 535 cubic feet. Complete log data was not recorded for the ponderosa pine, but the logs were slightly larger than the other species and had an approximate 7 inch average small end diameter. Table 1 gives the log diameters and knot size for the grand fir and lodgepole pine logs. Average large knot is the average of the largest knot measured in each of the four quadrants of a log. Individual log data is compiled in Appendix A-1 for grand fir, in Appendix B-1 for lodgepole pine, and in Appendix C-1 for ponderosa pine.

Table 1. Log size summary

	12 Foot Nominal Lengths			24 Foot Nominal Lengths		
	Large End Diameter (inches)	Small End Diameter (inches)	Average Large Knot (inches)	Large End Diameter (inches)	Small End Diameter (inches)	Average Large Knot (inches)
<b>Grand Fir</b>						
avg.	7	5	3/4	9	6	3/4
min.	6	4	1/2	7	4	1/4
max.	8	7	1	12	9	1 1/2
<b>Lodgepole Pine</b>						
avg.	6	5	3/4	9	6	3/4
min.	5	4	1/2	6	4	1/4
max.	7	6	1 1/4	12	8	1 1/4

## Gross Lumber Yield

Table 2 shows the volume of lumber produced at the sawmill before the boards were dried, planed, and graded. The target size of 12-foot 2x4's comprised 71 to 74 percent of total board volume produced.

Table 2. Gross lumber tally before planing, trimming, and grading.

### **Grand Fir**

Size	Piece Count	Volume (bf)	Size	Piece Count	Volume (bf)
2x4x12'	397	3176	1x4x12'	70	280
2x4x10'	60	400	1x4x10'	24	80
2x4x8'	58	309	1x4x8'	27	72
subtotal		<b>3885</b>	subtotal		<b>432</b>

Total board measure	<b>4317 board feet</b>
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### **Lodgepole Pine**

Size	Piece Count	Volume (bf)	Size	Piece Count	Volume (bf)
2x4x12'	306	2448	1x4x12'	77	308
2x4x10'	51	340	1x4x10'	30	100
2x4x8'	39	208	1x4x8'	15	40
subtotal		<b>2996</b>	subtotal		<b>448</b>

Total board measure	<b>3444 board feet</b>
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### **Ponderosa Pine**

Size	Piece Count	Volume (bf)	Size	Piece Count	Volume (bf)
2x4x12'	577	4616	1x4x12'	60	240
2x4x10'	112	747	1x4x10'	24	80
2x4x8'	104	555	1x4x8'	43	115
subtotal		<b>5917</b>	subtotal		<b>435</b>

Total board measure	<b>6352 board feet</b>
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### Visual Grade Yield

A summary of the visual grades is shown in Table 3. Board measure after visual grading is slightly less than gross board measure due to end trimming and broken or lost boards. The grand fir and lodgepole logs produced high quality lumber with over 70 percent of the 12-foot 2x4's falling into a visual grade of No.1 or Select Structural, and less than 4 percent were Economy grade. This high quality is attributed to small knot size. However, the ponderosa pine, with larger knots, produced over 50 percent Economy grade 12-foot 2x4's. This low grade recovery explains the Inland Northwest lumber manufacturing practice of utilizing ponderosa pine for shop grade boards rather than dimension lumber. Visual grades for individual 12-foot 2x4's are listed in Appendices A-2, B-2, and C-2 for grand fir, lodgepole pine, and ponderosa pine respectively.

Table 3. Lumber yield for visual grades.

	Piece Count			Volume (bf)
	2x4x12'	2x4x10'	2x4x8'	
Select Structural	29	3	1	257
No. 1	246	32	18	2277
No. 2	83	21	22	921
No. 3	14	4	6	171
Economy	15	2	19	235
Total	<b>387</b>	<b>62</b>	<b>66</b>	<b>3861</b>

	Piece Count			Volume (bf)
	2x4x12'	2x4x10'	2x4x8'	
Select Structural	35	10	9	395
No. 1	186	17	7	1639
No. 2	59	19	17	689
No. 3	13	5	2	148
Economy	4	2	10	99
Total	<b>297</b>	<b>53</b>	<b>45</b>	<b>2969</b>

	Piece Count			Volume (bf)
	2x4x12'	2x4x10'	2x4x8'	
Select Structural	1			8
No. 1	70	12		640
No. 2	173	20		1517
No. 3	16	3		148
Economy	282			2256
not graded		112	104	1301
Total	<b>542</b>	<b>147</b>	<b>104</b>	<b>5871</b>

The 1x4's were not graded but the sawmill estimated (11) the following yield with a 2½ percent end trim loss for lodgepole pine and grand fir:

3 Common - 80 percent

4 Common - 15 percent

5 Common - 5 percent

## Mechanical Properties

A typical loading curve for each of the three species is shown in Figure 1. This figure demonstrates the superior strength and stiffness characteristics that were typical of the lodgepole pine and grand fir when compared to the ponderosa pine group.

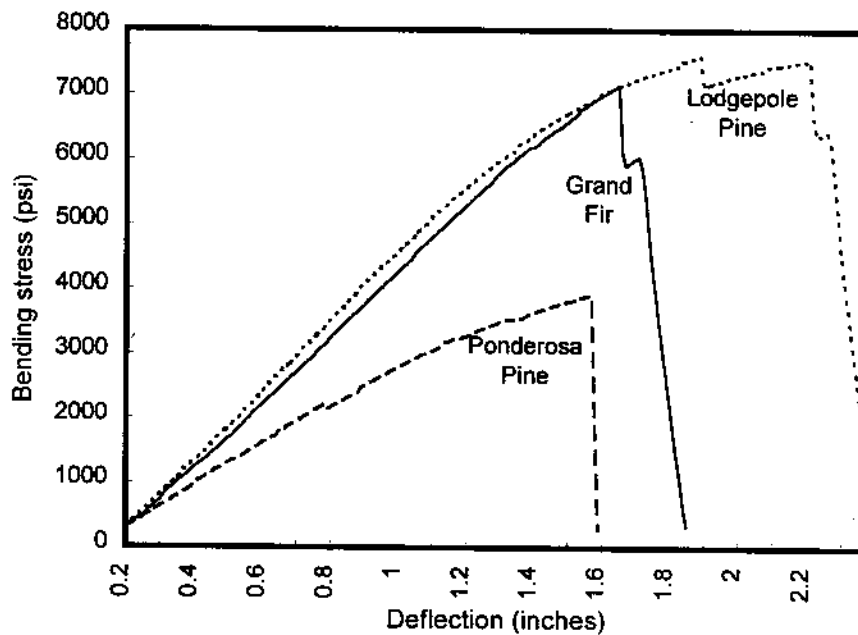


Figure 1. Stress vs. deflection plot for typical 2x4's.

The ponderosa pine sample group had 11.0 percent average MC and 0.352 average specific gravity. A preliminary analysis of the MOE indicates that all ponderosa pine pieces would fall below the 1650 Fb 1.5E MSR classification; therefore, since the sample had limited potential for MSR lumber, no further analysis was conducted.

Table 4 shows average mechanical properties of visual and MSR grade groups for grand fir and lodgepole pine. Complete data for mechanical properties of the grand fir and

lodgepole pine are shown in Appendices A-2 and B-2 respectively. The linear relationship of static and dynamic MOE is illustrated in Appendix A-3 for grand fir and in Appendix B-3 for lodgepole pine.

The grand fir group had an 11.5% average MC. For the grand fir 2000Fb-1.8E category the minimum MOE was 1.73 Mpsi, and the minimum MOE for 1650Fb-1.5E grade was 1.34 Mpsi. Both values are well above the 82% cutoff point. No pieces in the 2000Fb-1.8E grade category had an Fb less than 2.1 times design strength, and only three in the 1650Fb-1.5 E grade were below the 2.1 times Fb cutoff. No grand fir pieces were reduced in MSR grade due to visual characteristics.

The lodgepole pine had a 13.4% average MC. For the lodgepole pine 2400Fb-2.0E grade category the minimum MOE was  $1.87 \times 10^6$  psi, the minimum MOE for 2000Fb-1.8E grade was  $1.72 \times 10^6$  psi, and the minimum MOE for 1650Fb-1.5E grade was  $1.28 \times 10^6$  psi. All values were above the 82% cutoff point. No pieces in any grade category had an Fb less than 2.1 times design strength. Three pieces of lodgepole pine were removed from MSR grade due to visual characteristics.

The grand fir and lodgepole pine groups both have significantly higher average MOE and MOR for the select structural category compared to the lower visual grades. However, there is almost no difference in the MOE and MOR of the No.1, No.2, and No.3 grades. For example, the No.1 visually graded lodgepole pine 2x4's had an average MOE of  $1.47 \times 10^6$  psi and average MOR of 6530 psi which was lower than the MOE and MOR of both the No.2

and No.3 group. This is opposite what is expected given the higher design values of a No.1 grade, and it demonstrates the inherent difficulty in accurately predicting the mechanical properties of visually graded lumber.

Table 4. Mechanical properties for visual and MSR grades.

<b>Grand Fir</b>							
<u>Visual Grade</u>	Select Structural	No. 1	No. 2	No. 3	Total		
2x4x12' (qty.)	29	242	81	14	<b>366 pieces</b>		
Volume (bf)	232	1936	648	112	<b>2928 bf</b>		
Avg. MOE ( $10^6$ psi)	1.54	1.39	1.39	1.38	<b><math>1.40 \times 10^6</math> psi</b>		
Avg. MOR (psi)	8240	6720	6570	6250	<b>6790 psi</b>		
Avg. SG	0.342	0.345	0.348	0.341	<b>0.345</b>		
<u>MSR Grade</u>	2100Fb 1.8E	1650Fb 1.5E	No. 1	No. 2	No. 3	Total	
2x4x12' (qty.)	14	228	90	29	5	<b>366 pieces</b>	
Volume (bf)	112	1824	720	232	40	<b>2928 bf</b>	
Avg. MOE ( $10^6$ psi)	1.80	1.50	1.20	1.13	1.11	<b><math>1.40 \times 10^6</math> psi</b>	
Avg. MOR (psi)	8530	7240	5930	5460	4610	<b>6790 psi</b>	
Avg. SG	0.370	0.347	0.337	0.344	0.319	<b>0.345</b>	
<b>Lodgepole Pine</b>							
<u>Visual Grade</u>	Select Structural	No. 1	No. 2	No. 3	Total		
2x4x12' (qty.)	35	186	59	13	<b>293 pieces</b>		
Volume (bf)	280	1488	472	104	<b>2344 bf</b>		
Avg. MOE ( $10^6$ psi)	1.75	1.47	1.55	1.50	<b><math>1.52 \times 10^6</math> psi</b>		
Avg. MOR (psi)	8890	6530	7420	7010	<b>7010 psi</b>		
Avg. SG	0.428	0.400	0.413	0.411	<b>0.406</b>		
<u>MSR Grade</u>	2400Fb 2.0E	2100Fb 1.8E	1650Fb 1.5E	No. 1	No. 2	No. 3	Total
2x4x12' (qty.)	24	33	187	38	8	3	<b>293 pieces</b>
Volume (bf)	192	264	1496	304	64	24	<b>2344 bf</b>
Avg. MOE ( $10^6$ psi)	2.00	1.80	1.50	1.18	1.15	1.51	<b><math>1.52 \times 10^6</math> psi</b>
Avg. MOR (psi)	9760	8880	6750	5240	4950	8130	<b>7010 psi</b>
Avg. SG	0.471	0.436	0.400	0.381	0.364	0.404	<b>0.406</b>

### Grade Yield

A significant portion of both grand fir and lodgepole pine had mechanical properties high enough to be graded as MSR lumber. Sixty-six percent of the grand fir 12-foot 2x4's made MSR grade and 83% of the lodgepole pine 12-foot 2x4's were MSR grade. Figure 2 shows that an approximately equal proportion of No. 1, No.2, and No.3 visual grades made MSR grade. ALSC rules required that no select structural 2x4's could be produced as MSR grade residuals for this case. However, all visually graded select structural grand fir and lodgepole pine pieces made MSR grade, therefore, the ALSC rule had no effect on this study sample.

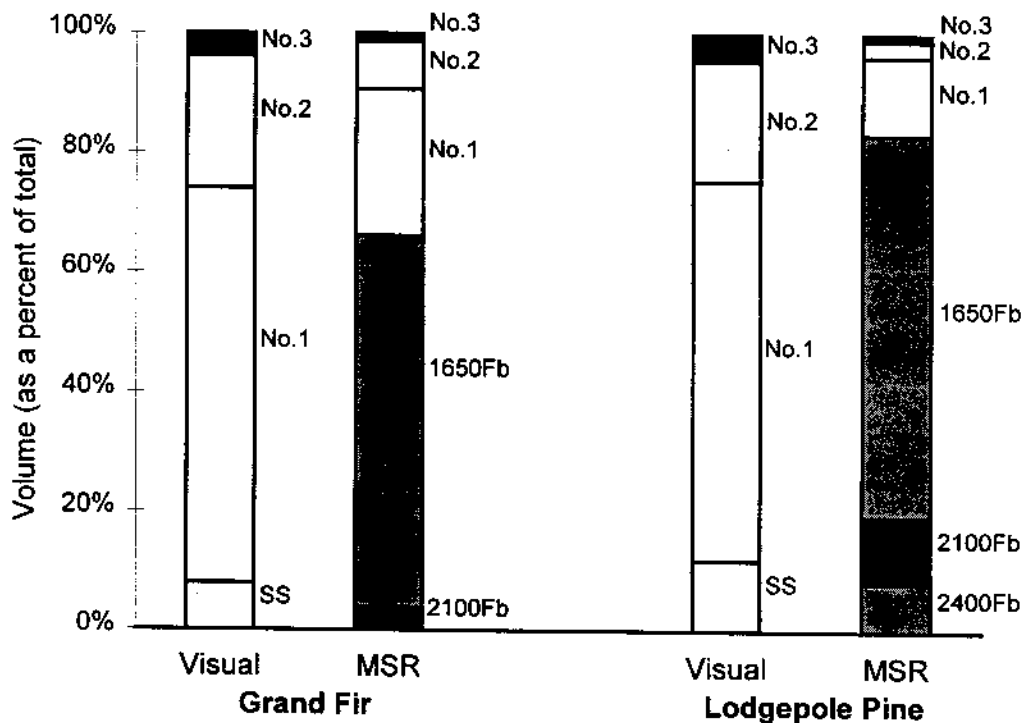


Figure 2. Yield comparison for visual and machine grading.



### Value Comparison

Table 5 shows the value comparison for the grand fir and lodgepole pine groups when graded visually or machine stress-rated with visual grade residuals. There is a \$15/Mbf increase in the value of grand fir when MSR grading is added, and the value increase for lodgepole pine is \$27/Mbf. The increase in value is attributable to the high percentage of No.3 visual grades which move into MSR categories. Sixty-four percent of the No.3 grand fir 2x4's and 77 percent of the No.3 lodgepole pine 2x4's moved into a MSR category.

Producing MSR lumber in categories below the 1650Fb - 1.5E level has diminishing economic return. As shown in Table 5 there is a significant quantity of #1 and #2 visual grades remaining after removal of MSR grades. The value of #1 and #2 is greater than that of the 1450Fb - 1.3 E. Therefore, it is not profitable in this case to produce any grades of MSR lower than 1650Fb - 1.5E.

Table 5. Value increase for machine stress-rating

**Grand Fir**

Grade	Price (\$/Mbf)	Visual Grade		Machine Stress-Rated	
		Volume (bf)	Value (\$)	Volume (bf)	Value (\$)
2100Fb 1.8E	\$425			112	\$48
Select Structural	\$425	232	\$99	0	\$0
1650Fb 1.5E	\$395			1824	\$720
No. 1	\$380	1936	\$736	720	\$274
No. 2	\$350	648	\$227	232	\$81
No. 3	\$240	112	\$27	40	\$10
Total		2928	\$1,088	2928	\$1,132

Increase in Value	\$15 /Mbf
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**Lodgepole Pine**

Grade	Price (\$/Mbf)	Visual Grade		Machine Stress-Rated	
		Volume (bf)	Value (\$)	Volume (bf)	Value (\$)
2400Fb 2.0E	\$475			192	\$91
2100Fb 1.8E	\$425			264	\$112
Select Str.	\$425	280	\$119	0	\$0
1650Fb 1.5E	\$395			1496	\$591
No. 1	\$380	1488	\$565	304	\$116
No. 2	\$350	472	\$165	64	\$22
No. 3	\$240	104	\$25	24	\$6
Total		2344	\$875	2344	\$938

Increase in Value	\$27 /Mbf
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## **Conclusions**

Small-diameter grand fir and lodgepole pine trees harvested from stagnated Inland Northwest forests may produce high quality visual grade lumber that has good mechanical properties. These favorable characteristics make them good candidates for machine stress-rating. At current prices, the addition of MSR grading equipment at an Inland Northwest sawmill could increase mill revenue \$27/Mbf for lodgepole pine 2x4's and \$15/Mbf for grand fir 2x4's. The results of this study can be used by sawmill owners to determine if the increase in mill revenue from MSR grading will be greater than the cost of installing and operating MSR grading equipment.

Ponderosa pine commercially thinned from Inland Northwest plantations does not yield lumber with mechanical properties or visual grades high enough to be utilized as dimension lumber.

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## **Appendix A**

### **Grand Fir Data**

Appendix A-1: Grand Fir Log Data.....	23
Appendix A-2: Grand Fir Visual Grades and Mechanical Properties.....	26
Appendix A-3: Static MOE vs. Dynamic MOE Regression.....	35

**Appendix A-1  
Grand Fir Log Data**

**12-foot nominal length**

	Large End Diameter (inches)	Small End Diameter (inches)	Largest Knot (inches)	Gross Volume (cubic feet)
	6	4	1	1.70
	7	4	1	2.13
	6	4	1	1.70
	6	5	1	2.00
	7	5	3/4	2.42
	7	5	1	2.42
	7	5	1	2.42
	8	6	1	3.27
	7	6	1	2.78
	8	6	1/2	3.27
	7	6	3/4	2.78
	7	6	1/2	2.78
	8	6	3/4	3.27
	8	7	1	3.70
average	7	5	1	
minimum	6	4	1/2	
maximum	8	7	1	
total				36.65 ft <sup>3</sup>

**24-foot nominal length**

	Large End Diameter (inches)	Small End Diameter (inches)	Largest Knot (inches)	Gross Volume (cubic feet)
	8	4	1	5.24
	8	4	1 1/4	5.24
	7	4	1	4.25
	7	4	3/4	4.25
	7	4	3/4	4.25
	7	4	3/4	4.25
	7	4	3/4	4.25
	8	5	1/2	5.83
	7	5	1/2	4.84
	8	5	1 1/4	5.83
	9	5	3/4	6.94
	7	5	1 1/2	4.84
	8	5	1	5.83
	9	5	1	6.94
	7	5	3/4	4.84
	7	5	1 1/4	4.84
	7	5	3/4	4.84
	9	5	1 1/4	6.94

**Appendix A-1  
Grand Fir Log Data**

24-foot nominal length			
Large End Diameter (inches)	Small End Diameter (inches)	Largest Knot (inches)	Gross Volume (cubic feet)
8	5	1	5.83
10	6	3/4	8.90
7	6	3/4	5.56
7	6	5/8	5.56
8	6	3/4	6.54
8	6	1	6.54
8	6	3/4	6.54
8	6	1 1/4	6.54
9	6	1	7.66
8	6	3/4	6.54
8	6	1	6.54
8	6	3/4	6.54
10	6	1	8.90
7	6	3/4	5.56
9	6	1	7.66
8	6	3/4	6.54
10	6	1/2	8.90
9	6	1/4	7.66
8	6	3/4	6.54
9	7	1/2	8.51
10	7	5/8	9.75
9	7	3/4	8.51
9	7	3/4	8.51
10	7	3/4	9.75
10	7	1	9.75
9	7	1	8.51
8	7	3/4	7.40
10	7	3/4	9.75
9	7	3/4	8.51
9	7	3/4	8.51
11	7	1/2	11.13
10	7	3/4	9.75
9	7	3/4	8.51
10	8	3/4	10.73
11	8	3/4	12.11
11	8	1	12.11
10	8	3/4	10.73
11	8	1 1/2	12.11
12	8	3/4	13.61



**Appendix A-1  
Grand Fir Log Data**

<b>24-foot nominal length</b>				
	<b>Large End Diameter (inches)</b>	<b>Small End Diameter (inches)</b>	<b>Largest Knot (inches)</b>	<b>Gross Volume (cubic feet)</b>
	9	8	3/4	9.49
	11	8	1	12.11
	10	8	1	10.73
	12	9	1	14.73
	11	9	3/4	13.22
	12	9	1/2	14.73
average	9	6	3/4	
minimum	7	4	1/4	
maximum	12	9	1 1/2	
total				498.60 ft <sup>3</sup>

<b>Total Gross Log Volume</b>	<b>535.25 ft<sup>3</sup></b>
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**Appendix A-2**  
**Grand Fir Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
70	1.83	1.89	10176	2	hc	1/6	11.5	0.357
112	1.91	1.88	8877	ss		1/6	12.1	0.363
121	1.99	1.84	9072	1	ok	1/6	12.4	0.390
104	1.87	1.83	7148	3	w	1/6	11.6	0.372
186	1.98	1.81	8818	2	w	1/6	10.6	0.396
241	1.84	1.80	5967	1	xs	1/6	11.2	0.378
297	1.69	1.79	7783	1	xs	1/6	11.8	0.386
99	1.99	1.79	9668	1	xs	1/6	12.0	0.372
69	1.79	1.77	8877	3	w	1/6	12.1	0.375
295	1.81	1.77	9287	ss		1/6	10.2	0.298
119	1.89	1.76	9170	1	xs	1/6	11.9	0.379
235	1.78	1.75	6738	1	xs	1/6	10.5	0.357
6	1.82	1.74	9678	1	xs	1/6	12.4	0.347
328	1.86	1.73	9000	1	xs	1/6	13.1	0.407
end of 2100 Fb - 1.80E grade								
301	1.69	1.72	9199	ss		1/6	12.2	0.397
82	1.70	1.72	7324	1	xs	1/6	11.8	0.417
265	1.96	1.71	5791	1	xs	1/6	9.9	0.360
254	1.72	1.70	8945	1	xs	1/6	12.0	0.409
45	1.63	1.70	10205	1	xs	1/6	12.9	0.413
249	1.84	1.69	9229	1	xs	1/6	10.5	0.360
92	1.72	1.69	8623	2	ws	1/6	11.5	0.373
110	1.91	1.69	7549	1	ok	1/6	11.5	0.371
60	1.63	1.68	8145	2	w	1/6	11.9	0.360
141	1.57	1.68	8560	1	xs	1/6	11.4	0.385
147	1.53	1.68	9941	2	w	1/6	11.3	0.382
140	1.82	1.68	8594	ss		1/6	10.5	0.332
224	1.88	1.67	7871	1	ok	1/6	11.0	0.341
77	1.69	1.67	9707	1	xs	1/6	11.9	0.353
286	1.66	1.67	7695	1	ok	1/6	11.4	0.339
192	1.75	1.67	6973	1	xs	1/6	9.6	0.353
269	1.40	1.67	8818	1	xs	1/6	11.2	0.348
354	1.56	1.67	9316	1	xs	1/6	12.6	0.389
253	1.72	1.66	9482	ss		1/6	10.1	0.358
173	1.91	1.66	5527	1	ok	1/6	10.6	0.359
85	1.70	1.66	9189	1	xs	1/6	12.0	0.360
20	1.71	1.66	8848	1	xs	1/6	12.4	0.361
238	1.71	1.66	9680	ss		1/6	11.5	0.342
351	1.57	1.65	8809	1	xs	1/6	13.1	0.373
233	1.80	1.65	9521	1	xs	1/6	12.2	0.379
157	1.71	1.65	7637	1	ok	1/6	9.7	0.358
304	1.77	1.65	8730	1	xs	1/6	12.6	0.384

**Appendix A-2**  
**Grand Fir Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
187	1.63	1.65	5430	1	xs	1/6	10.5	0.360
337	1.74	1.65	8359	1	xs	1/6	12.4	0.335
32	1.69	1.65	9229	ss		1/6	12.4	0.356
14	1.66	1.64	7988	2	w	1/6	11.5	0.352
212	1.75	1.64	8994	2	w	1/6	11.1	0.336
97	1.72	1.64	8184	1	xs	1/6	12.1	0.348
220	1.72	1.64	8135	1	xs	1/6	10.1	0.397
199	1.68	1.63	9063	2	w	1/6	10.4	0.383
88	1.70	1.63	8135	2	ws	1/6	12.6	0.382
275	1.47	1.63	9092	1	xs	1/6	10.6	0.375
374	1.71	1.63	8691	ss		1/6	12.4	0.330
349	1.65	1.62	7305	2	w	1/6	11.2	0.326
143	1.74	1.62	7666	1	xs	1/6	10.9	0.347
350	1.66	1.62	9121	1	xs	1/6	13.1	0.389
28	1.66	1.62	5381	2	w	1/6	12.1	0.348
89	1.65	1.62	9365	1	xs	1/6	11.7	0.352
321	1.69	1.62	6523	2	w	1/6	12.1	0.362
2	1.66	1.62	7842	1	xs	1/6	10.6	0.338
1	1.63	1.61	8398	2	w+ws	1/6	12.2	0.366
344	1.73	1.61	6514	ss		1/6	12.1	0.332
206	1.92	1.61	8447	ss		1/6	10.5	0.361
86	1.56	1.61	7139	2	hc	1/6	13.0	0.366
49	1.66	1.61	8027	3	spl	1/6	12.7	0.333
268	1.74	1.61	7178	1	xs	1/6	11.1	0.341
117	1.56	1.60	8203	2	ws+hc	1/6	12.1	0.398
101	1.61	1.60	7861	2	w	1/6	12.0	0.373
263	1.63	1.60	8584	ss		1/6	12.3	0.369
52	1.51	1.59	7285	2	ws	1/6	12.5	0.352
54	1.55	1.59	6699	1	xs	1/6	12.1	0.374
331	1.64	1.59	5586	1	xs	1/6	10.8	0.335
296	1.68	1.59	8711	1	xs	1/6	11.2	0.334
50	1.61	1.59	6982	2	w	1/6	12.9	0.354
204	1.53	1.59	8271	ss		1/6	11.0	0.364
118	1.63	1.58	8760	ss		1/6	11.7	0.357
211	1.61	1.58	7666	1	xs	1/6	11.0	0.331
259	1.77	1.58	2302	1	ok	1/6	11.1	0.364
79	1.60	1.58	5518	1	xs	1/6	11.0	0.343
267	1.60	1.57	7402	2	xs	1/6	10.5	0.379
71	1.56	1.57	8467	1	xs	1/6	12.3	0.343
114	1.53	1.57	6416	2	ws	1/6	12.9	0.368
214	1.74	1.57	8320	1	xs	1/6	9.8	0.310
59	1.64	1.57	7256	1	xs	1/6	12.4	0.344
380	1.58	1.56	6680	2	w	1/6	11.4	0.318

**Appendix A-2**  
**Grand Fir Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
125	1.43	1.56	7080	2	w	1/6	12.5	0.400
170	1.65	1.56	8330	ss		1/6	10.5	0.357
162	1.43	1.56	7627	1	xs	1/6	10.3	0.358
133	1.67	1.55	9756	ss		1/6	12.3	0.411
144	1.52	1.55	8711	1	xs	1/6	10.2	0.361
74	1.48	1.55	7490	1	xs	1/6	11.8	0.321
113	1.67	1.55	6230	2	xs	1/6	12.4	0.388
93	1.58	1.55	7969	2	w	1/6	11.7	0.336
108	1.69	1.54	6338	1	xs	1/6	12.0	0.341
333	1.66	1.54	7998	ss		1/6	12.1	0.342
209	1.51	1.54	9375	1	xs	1/6	11.0	0.366
205	1.54	1.54	8115	1	ok	1/6	9.6	0.333
290	1.57	1.54	6221	2	w	1/6	12.3	0.329
53	1.49	1.54	7998	1	xs	1/6	12.0	0.351
277	1.49	1.53	6426	1	ok	1/6	11.3	0.397
319	1.71	1.53	4492	2	w	1/6	11.7	0.359
169	1.45	1.53	8975	2	w	1/6	10.9	0.349
155	1.47	1.53	8600	1	xs	1/6	10.7	0.330
120	1.59	1.52	7061	2	w	1/6	11.8	0.358
219	1.56	1.52	7236	1	xs	1/6	11.0	0.379
231	1.51	1.52	8516	1	xs	1/6	12.1	0.389
30	1.69	1.52	5879	1	xs	1/6	12.5	0.336
18	1.61	1.52	8125	1	xs	1/6	12.7	0.330
68	1.62	1.51	7412	1	xs	1/6	10.9	0.351
128	1.66	1.51	7744	2	w	1/6	11.9	0.318
234	1.58	1.51	7852	2	w	1/6	11.4	0.336
106	1.50	1.51	7813	1	xs	1/6	10.9	0.328
22	1.50	1.50	7900	1	xs	1/6	12.4	0.337
43	1.51	1.50	8564	1	xs	1/6	12.0	0.346
172	1.51	1.50	7178	1	xs	1/6	10.5	0.335
305	1.56	1.50	6641	ss		1/6	12.5	0.331
294	1.58	1.50	3359	1	xs	1/6	11.7	0.364
145	1.36	1.50	8398	1	xs	1/6	11.4	0.379
7	1.56	1.49	7607	1	xs	1/6	11.7	0.342
51	1.55	1.49	8750	ss		1/6	12.4	0.336
353	1.46	1.49	6055	1	xs	1/6	11.6	0.324
42	1.44	1.49	6162	1	xs	1/6	11.7	0.391
195	1.52	1.49	6299	2	w	1/6	9.6	0.336
36	1.51	1.49	7090	1	xs	1/6	12.0	0.315
40	1.54	1.48	7998	1	xs	1/6	11.1	0.312
33	1.46	1.48	8164	ss		1/6	13.0	0.348
17	1.61	1.48	7480	2	w	1/6	12.4	0.338
262	1.46	1.48	6855	1	xs	1/6	11.1	0.368

**Appendix A-2**  
**Grand Fir Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
98	1.37	1.48	8174	1	xs	1/6	11.9	0.358
142	1.55	1.48	8643	1	xs	1/6	10.4	0.330
90	1.58	1.48	6729	2	w	1/6	10.9	0.327
132	1.53	1.47	5068	1	xs	1/6	11.6	0.328
154	1.51	1.47	8428	1	xs	1/6	9.7	0.346
31	1.49	1.47	6367	3	dec	1/6	13.0	0.377
139	1.34	1.46	6855	3	dec	1/6	10.9	0.335
213	1.39	1.46	6064	1	xs	1/6	10.2	0.348
270	1.41	1.46	7705	2	es	1/6	10.3	0.337
285	1.62	1.46	5830	1	xs	1/6	11.8	0.347
281	1.48	1.46	7227	3	w	1/6	11.4	0.369
314	1.55	1.46	6328	2	es	1/6	11.7	0.369
288	1.55	1.46	8594	ss		1/6	12.5	0.320
166	1.26	1.46	6172	1	xs	1/6	11.5	0.400
229	1.51	1.46	5947	1	xs	1/6	10.0	0.344
325	1.53	1.45	8320	1	ok	1/6	11.6	0.304
232	1.47	1.45	7031	1	xs	1/6	11.4	0.337
329	1.46	1.45	7969	1	xs	1/6	11.7	0.331
243	1.48	1.45	5684	1	xs	1/6	11.4	0.309
12	1.55	1.45	5225	1	xs	1/6	12.0	0.354
83	1.40	1.44	3477	1	xs	1/6	11.5	0.400
343	1.37	1.44	7051	1	xs	1/6	11.3	0.352
356	1.46	1.44	7627	1	xs	1/4	10.8	0.306
364	1.46	1.44	7871	1	xs	1/6	12.7	0.366
91	1.46	1.44	6602	2	w	1/6	11.2	0.310
105	1.46	1.44	6934	3	w	1/6	11.3	0.310
27	1.46	1.44	5947	2	w	1/6	11.3	0.320
167	1.44	1.44	5215	2	w	1/6	10.5	0.354
287	1.53	1.44	6943	1	xs	1/6	11.5	0.319
279	1.40	1.44	6611	1	xs	1/6	11.1	0.344
23	1.50	1.44	7832	1	xs	1/6	12.7	0.329
38	1.47	1.43	6846	1	xs	1/6	11.8	0.328
228	1.55	1.43	6963	ss		1/6	10.1	0.288
126	1.44	1.43	7393	1	ok	1/6	12.2	0.355
227	1.25	1.43	7227	1	xs	1/6	11.0	0.363
75	1.43	1.43	6592	1	xs	1/6	10.5	0.337
377	1.43	1.43	7246	1	xs	1/6	12.2	0.335
317	1.50	1.43	6816	1	xs	1/6	11.6	0.322
4	1.44	1.43	6514	1	xs	1/6	12.8	0.336
347	1.44	1.43	5234	2	shk	1/6	13.0	0.328
11	1.32	1.42	4375	1	xs	1/6	12.4	0.352
185	1.64	1.42	5508	1	xs	1/6	10.7	0.330
156	1.45	1.42	5908	1	xs	1/6	11.0	0.342

**Appendix A-2**  
**Grand Fir Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
182	1.34	1.42	5850	1	xs	1/6	11.1	0.339
78	1.34	1.42	8330	1	xs	1/6	12.3	0.358
109	1.45	1.42	5693	1	xs	1/6	12.0	0.325
24	1.33	1.42	8350	ss		1/6	12.1	0.333
291	1.43	1.42	6475	1	xs	1/6	11.8	0.338
326	1.42	1.42	8203	ss		1/6	11.8	0.327
168	1.51	1.41	6064	2	shk	1/6	11.3	0.376
149	1.49	1.41	5645	2	w	1/6	10.0	0.313
362	1.47	1.41	6768	1	xs	1/6	10.6	0.304
136	1.53	1.41	4287	1	xs	1/6	10.1	0.329
302	1.65	1.41	5840	1	xs	1/6	12.4	0.397
355	1.46	1.41	4775	1	xs	1/6	11.8	0.321
64	1.54	1.41	7070	2	w	1/6	10.4	0.302
171	1.45	1.41	6846	1	xs	1/6	10.5	0.315
174	1.30	1.41	8701	1	xs	1/6	11.3	0.364
217	1.47	1.40	7227	3	spl	1/6	11.6	0.351
135	1.48	1.40	6221	1	xs	1/6	10.7	0.309
363	1.44	1.40	5508	1	xs	1/6	12.0	0.305
193	1.32	1.40	7256	1	xs	1/6	10.5	0.384
324	1.62	1.40	6396	1	xs	1/6	12.5	0.349
176	1.28	1.40	7061	1	xs	1/6	11.4	0.364
271	1.37	1.40	6738	1	xs	1/6	11.6	0.330
257	1.29	1.40	6982	1	xs	1/6	10.5	0.361
274	1.24	1.40	7139	1	xs	1/6	11.2	0.355
15	1.28	1.40	7080	1	xs	1/6	11.3	0.344
115	1.53	1.40	6982	ss		1/6	11.9	0.307
26	1.32	1.39	7246	1	xs	1/6	12.1	0.328
230	1.38	1.39	5195	1	ok	1/6	9.9	0.325
61	1.31	1.39	7656	2	ws	1/6	12.9	0.342
289	1.42	1.39	7021	1	xs	1/6	12.2	0.335
278	1.49	1.39	8047	ss		1/6	11.4	0.380
134	1.29	1.39	7197	2	es	1/6	12.3	0.325
102	1.42	1.38	7734	1	xs	1/6	11.0	0.331
200	1.21	1.38	7695	2	hc	1/6	11.2	0.389
245	1.32	1.38	6709	1	xs	1/6	12.0	0.325
37	1.42	1.38	4648	2	w	1/6	12.0	0.344
247	1.40	1.38	6689	1	xs	1/6	11.6	0.367
352	1.42	1.38	7109	1	xs	1/6	10.9	0.363
146	1.54	1.38	6729	ss		1/6	10.4	0.298
266	1.35	1.38	5840	2	ws	1/6	11.4	0.327
107	1.39	1.38	6846	1	xs	1/6	10.7	0.366
153	1.30	1.38	7334	1	xs	1/6	9.6	0.367
103	1.41	1.37	5918	1	xs	1/6	11.4	0.313

**Appendix A-2**  
**Grand Fir Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
340	1.36	1.37	7197	1	xs	1/6	12.2	0.329
226	1.35	1.37	5879	2	w	1/6	10.6	0.309
100	1.26	1.36	7012	2	wrp	1/6	12.2	0.331
39	1.28	1.36	7354	1	xs	1/6	12.1	0.329
63	1.39	1.36	7139	1	xs	1/6	11.2	0.309
303	1.36	1.35	8711	1	xs	1/6	12.1	0.352
345	1.42	1.35	7305	1	xs	1/6	10.8	0.303
137	1.41	1.35	7334	2	md	1/6	10.8	0.337
299	1.37	1.35	6719	1	xs	1/6	10.9	0.322
251	1.45	1.35	6455	1	xs	1/6	10.9	0.310
5	1.35	1.35	7793	2	es	1/6	12.2	0.319
318	1.45	1.35	7607	2	w	1/6	12.1	0.348
372	1.39	1.35	5830	1	xs	1/6	12.8	0.330
239	1.30	1.34	8223	1	xs	1/6	11.9	0.370
81	1.21	1.34	5820	3	dec	1/6	11.6	0.362
298	1.29	1.34	8447	1	xs	1/6	11.7	0.337
111	1.27	1.34	6934	1	xs	1/6	12.0	0.399
66	1.34	1.34	6338	1	xs	1/6	10.4	0.284
368	1.54	1.34	4521	1	xs	1/6	11.8	0.308
361	1.45	1.34	5947	1	xs	1/6	12.3	0.341
312	1.45	1.34	8066	ss		1/6	12.6	0.305
210	1.40	1.34	6064	1	xs	1/6	10.8	0.315
341	1.31	1.33	7041	1	xs	1/6	13.8	0.354
129	1.32	1.33	4590	1	xs	1/6	12.5	0.389
332	1.23	1.32	6787	1	xs	1/6	11.1	0.344
264	1.21	1.32	6465	ss		1/6	12.2	0.350
307	1.32	1.32	5527	1	xs	1/6	12.2	0.318
313	1.38	1.32	7188	ss		1/6	11.4	0.319
327	1.34	1.32	7100	1	xs	1/6	11.2	0.320
end of 1650Fb - 1.5 E grade								
35	1.25	1.32	5869	1	xs	1/6	11.8	0.330
379	1.33	1.32	5703	1	xs	1/6	12.9	0.352
315	1.41	1.32	6934	1	xs	1/6	12.7	0.305
261	1.34	1.31	7783	1	ok	1/6	10.4	0.338
127	1.55	1.31	3457	1	ok	1/6	11.0	0.317
218	1.42	1.31	7402	1	xs	1/6	10.3	0.300
381	1.53	1.31	3926	1	ok	1/6	12.3	0.338
342	1.30	1.31	7969	1	xs	1/6	13.2	0.355
76	1.46	1.31	5742	1	xs	1/6	11.0	0.333
284	1.26	1.30	6201	1	xs	1/6	11.7	0.341
334	1.41	1.30	4199	1	ok	1/6	11.0	0.337
255	1.32	1.30	5508	1	xs	1/6	11.4	0.349

**Appendix A-2**  
**Grand Fir Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
94	1.11	1.29	7236	1	xs	1/6	11.9	0.393
13	1.34	1.29	4707	1	xs	1/6	12.0	0.318
8	1.26	1.29	6738	1	xs	1/6	13.3	0.334
357	1.37	1.29	8193	1	xs	1/6	10.4	0.350
320	1.39	1.29	6045	1	ok	1/6	12.1	0.331
358	1.18	1.29	7305	1	xs	1/6	10.9	0.353
124	1.18	1.29	3525	1	xs	1/6	12.2	0.335
9	1.18	1.29	5703	1	xs	1/6	12.9	0.336
122	1.28	1.28	5547	1	xs	1/6	12.3	0.331
46	1.25	1.28	5342	1	xs	1/6	12.3	0.311
55	1.41	1.28	4971	1	xs	1/6	12.0	0.303
161	1.26	1.28	6689	1	xs	1/6	10.8	0.321
183	1.39	1.28	7139	1	ok	1/6	10.7	0.357
96	1.21	1.28	5674	1	xs	1/6	11.5	0.295
48	1.21	1.27	4434	1	xs	1/6	12.9	0.322
58	1.19	1.27	7217	1	xs	1/6	12.8	0.364
280	1.21	1.27	6133	1	xs	1/6	11.0	0.300
152	1.26	1.26	7510	1	xs	1/6	9.9	0.317
208	1.23	1.26	6045	1	xs	1/6	10.7	0.333
207	1.35	1.25	5645	1	xs	1/6	10.7	0.309
151	1.27	1.25	7471	1	xs	1/6	9.4	0.300
236	1.40	1.25	4648	1	xs	1/6	9.7	0.310
250	1.36	1.25	4746	1	xs	1/6	10.5	0.329
95	1.16	1.25	5166	1	xs	1/6	12.2	0.356
252	1.17	1.25	8164	1	xs	1/6	11.6	0.380
376	1.27	1.25	6182	1	xs	1/6	12.4	0.354
34	1.12	1.25	5938	1	xs	1/6	11.9	0.358
198	1.26	1.24	6035	1	xs	1/6	9.8	0.304
131	1.18	1.24	8560	1	xs	1/6	11.8	0.338
336	1.25	1.24	5508	1	xs	1/6	11.8	0.327
202	1.18	1.24	6348	1	xs	1/6	11.1	0.332
258	1.20	1.24	5518	1	xs	1/6	10.9	0.310
16	1.14	1.24	7158	1	xs	1/6	12.7	0.386
163	1.27	1.23	5703	1	xs	1/6	11.1	0.322
223	1.25	1.23	7051	1	ok	1/6	11.5	0.378
189	1.19	1.23	6221	1	xs	1/6	10.5	0.324
260	1.20	1.22	4756	1	xs	1/6	10.1	0.327
148	1.10	1.21	5664	1	xs	1/6	10.7	0.343
367	1.23	1.21	6318	1	xs	1/6	13.2	0.389
316	1.27	1.21	4316	1	xs	1/6	12.1	0.342
10	1.25	1.21	5605	1	xs	1/6	11.7	0.320
56	1.17	1.20	7324	1	xs	1/6	13.0	0.340
382	1.32	1.20	8945	1	xs	1/6	12.6	0.390



**Appendix A-2**  
**Grand Fir Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
365	1.22	1.20	7305	1	xs	1/6	12.5	0.324
323	1.10	1.19	6045	1	xs	1/6	12.6	0.386
197	1.19	1.19	5664	1	xs	1/6	10.4	0.302
373	1.19	1.19	6016	1	xs	1/6	13.0	0.306
360	1.19	1.19	5117	1	xs	1/6	13.1	0.331
306	1.16	1.19	5664	1	xs	1/6	12.8	0.369
222	1.28	1.18	4141	1	xs	1/6	9.5	0.316
215	1.23	1.18	4707	1	xs	1/6	10.9	0.299
237	1.22	1.17	6250	1	xs	1/6	11.1	0.333
348	1.16	1.17	5098	1	xs	1/6	12.4	0.290
158	1.13	1.16	4854	1	xs	1/6	10.6	0.362
272	1.13	1.16	5371	1	xs	1/6	10.8	0.315
160	1.06	1.15	6953	1	xs	1/6	10.6	0.378
246	1.15	1.15	6787	1	xs	1/6	10.9	0.348
346	1.22	1.15	6035	1	xs	1/6	13.6	0.308
283	1.10	1.14	5137	1	xs	1/6	11.7	0.305
322	1.09	1.14	5684	1	xs	1/6	11.9	0.331
201	1.04	1.13	7559	1	xs	1/6	10.9	0.368
276	1.10	1.12	4570	1	xs	1/6	10.4	0.306
293	1.06	1.10	5781	1	xs	1/6	12.1	0.305
310	1.27	1.10	4463	1	xs	1/6	10.9	0.339
84	1.12	1.10	5293	1	xs	1/6	11.7	0.327
73	1.05	1.09	6338	1	xs	1/6	11.5	0.381
21	1.07	1.09	5361	1	xs	1/6	12.4	0.346
273	0.99	1.08	6953	1	xs	1/6	11.3	0.369
300	1.03	1.08	4834	1	xs	1/6	11.9	0.337
191	1.10	1.05	4043	1	xs	1/6	10.4	0.316
178	0.98	1.01	4297	1	xs	1/6	10.7	0.339
116	1.05	1.00	6328	1	xs	1/6	12.2	0.357
179	0.94	0.97	4238	1	xs	1/6	9.5	0.325
180	0.91	0.97	7148	1	xs	1/6	9.4	0.329
359	0.87	0.92	7080	1	xs	1/6	13.4	0.365
339	0.96	0.90	5742	1	xs	1/6	12.9	0.426
150	0.75	0.85	5488	1	xs	1/6	11.6	0.361
190	0.76	0.74	5430	1	xs	1/6	9.7	0.384
240	1.47	1.31	5078	2	w	1/6	10.7	0.294
335	1.43	1.31	4814	2	w	1/6	12.0	0.322
370	1.27	1.31	6943	2	dec	1/6	12.2	0.360
369	1.29	1.29	5830	2	w	1/6	12.5	0.372
184	1.04	1.26	8096	2	wrp	1/6	10.8	0.330
371	1.24	1.25	6230	2	sp	1/6	12.0	0.300
44	1.28	1.25	5361	2	spl	1/6	10.7	0.299
309	1.34	1.23	3418	2	w	1/6	12.1	0.320

**Appendix A-2**  
**Grand Fir Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
3	1.26	1.23	6934	2	w	1/6	13.9	0.384
29	1.18	1.22	7178	2	ws	1/6	12.6	0.355
225	1.33	1.21	4189	2		1/6	11.4	0.328
256	1.07	1.21	6631	2	w	1/6	11.3	0.384
375	1.23	1.21	3330	2	w	1/6	11.2	0.316
221	1.14	1.20	7061	2	xs	1/4	10.9	0.395
378	1.19	1.19	3857	2	w	1/6	13.0	0.369
248	1.15	1.16	4912	2	w	1/4	10.8	0.351
177	1.24	1.14	4268	2	w	1/6	9.9	0.278
188	1.03	1.12	4102	2	slp	1/6	10.5	0.324
130	1.13	1.11	6855	2	w	1/6	12.1	0.360
244	0.96	1.09	6934	2	shk	1/6	12.2	0.382
164	1.11	1.08	3955	2	hc	1/6	10.4	0.366
366	1.25	1.07	5137	2	ws	1/6	12.0	0.399
181	0.98	1.06	4023	2	ws+hc	1/6	8.9	0.350
47	1.02	1.05	5723	2	slp	1/6	13.1	0.336
138	0.89	0.94	4873	2	ws+hc	1/6	10.0	0.349
311	0.83	0.88	5977	2	ws	1/6	11.8	0.329
19	0.87	0.87	5352	2	ws	1/6	12.3	0.343
292	0.90	0.84	4023	2	w	1/6	12.9	0.368
123	0.76	0.76	7266	2	w+wrp	1/6	11.8	0.313
165	1.30	1.28	4785	3	shk	1/6	11.1	0.368
62	1.17	1.23	6006	3	w	1/6	10.9	0.295
175	1.17	1.18	4268	3	dec	1/6	9.1	0.308
25	1.13	1.06	5244	3	dec	1/6	11.7	0.322
194	0.83	0.81	2734	3	dec	1/6	8.3	0.305
338	NA	1.20	6201	1	xs	1/6	12.7	0.359
72	NA	1.82	7666	1	xs	1/6	12.7	0.372
57	1.39	NA	8184	2	w	1/6	12.2	0.384
308	1.80	NA	0	2	w	1/6	12.0	0.386
196	1.29	NA	9084	1	xs	1/6	10.4	0.342
282	1.46	NA	5469	1	ok	1/6	10.9	0.317
average	1.42	1.40	6792				11.5	0.345

Note: Shaded area is not included in analysis.

**Key to Visual Characteristic Code**

(This is the characteristic which limited the board to its assigned grade category.)

dec decay	ok other knot	w wane
es edge skip	shk shake	wrp warp
hc honeycomb	slp slope of grain	ws white speck
md machine damage	spl split	xs cross section

## Appendix A-3

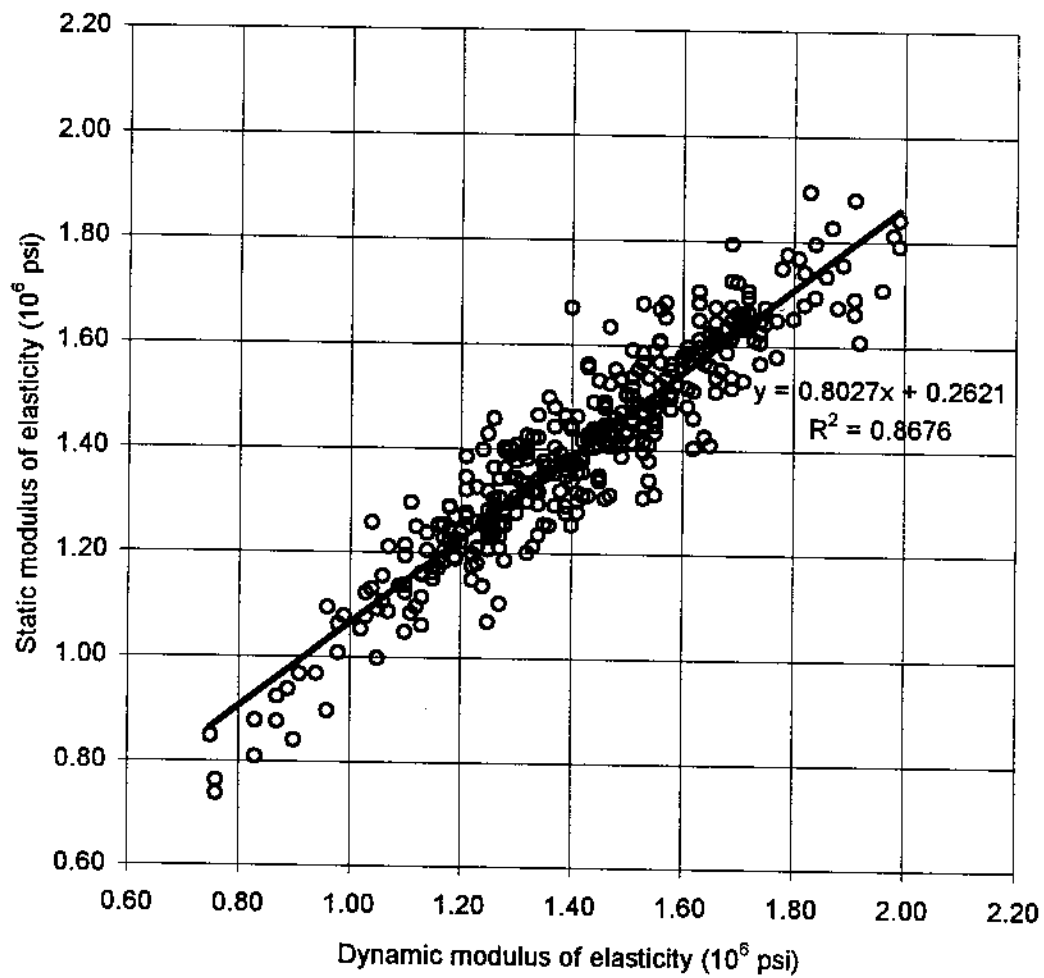


Figure 3. Static modulus of elasticity vs. dynamic modulus of elasticity for grand fir sample.

## **Appendix B**

### **Lodgepole Pine Data**

Appendix B-1: Lodgepole Pine Log Data .....	37
Appendix B-2: Lodgepole Pine Visual Grades and Mechanical Properties .....	39
Appendix B-3: Static MOE vs. Dynamic MOE Regression.....	46

**Appendix A-1  
Lodgepole Pine Log Data**

<b>12-foot nominal length</b>				
	Large End Diameter (inches)	Small End Diameter (inches)	Largest Knot (inches)	Gross Volume (cubic feet)
	6	4	1	1.70
	6	5	3/4	2.00
	6	5	3/4	2.00
	6	5	3/4	2.00
	6	5	1 1/4	2.00
	6	5	3/4	2.00
	7	5	1 1/4	2.42
	5	5	1/2	1.64
	6	5	3/4	2.00
	6	5	1 1/4	2.00
	6	5	3/4	2.00
	6	5	3/4	2.00
	6	5	3/4	2.00
	7	6	1/2	2.78
average	6	5	3/4	
minimum	5	4	1/2	
maximum	7	6	1 1/4	
total				28.5 ft <sup>3</sup>

<b>24-foot nominal length</b>				
	Large End Diameter (inches)	Small End Diameter (inches)	Largest Knot (inches)	Gross Volume (cubic feet)
	7	4	1	4.25
	8	5	5/8	5.83
	8	5	1/2	5.83
	7	5	1	4.84
	7	5	3/4	4.84
	8	5	1/2	5.83
	7	5	1	4.84
	8	5	1/2	5.83
	9	5	3/4	6.94
	7	5	1 1/4	4.84
	8	5	1	5.83
	8	5	1/2	5.83
	10	5	1 1/4	8.18
	7	5	1	4.84
	7	5	1	4.84
	9	5	1/2	6.94
	7	5	1/4	4.84
	7	5	1	4.84
	7	5	1 1/4	4.84

**Appendix A-1**  
**Lodgepole Pine Log Data**  
**24-foot nominal length**

Large End Diameter (inches)	Small End Diameter (inches)	Largest Knot (inches)	Gross Volume (cubic feet)	
6	5	3/4	3.99	
7	5	3/4	4.84	
9	6	1/2	7.66	
10	6	1/2	8.90	
9	6	1	7.86	
8	6	1	6.54	
8	6	3/4	6.54	
8	6	1/2	6.54	
8	6	1/2	6.54	
9	6	1/2	7.66	
10	6	3/8	8.90	
8	6	1/2	6.54	
8	6	1/2	6.54	
9	6	1/2	7.66	
9	6	1/4	7.66	
9	6	3/4	7.66	
9	6	3/4	7.66	
8	6	3/4	6.54	
9	6	1/2	7.66	
8	6	1/2	6.54	
9	6	1	7.66	
10	7	1/2	9.75	
10	7	1/2	9.75	
11	7	1	11.13	
11	7	1/2	11.13	
10	7	3/4	9.75	
9	7	3/4	8.51	
11	7	3/4	11.13	
11	7	1/4	11.13	
10	7	1/2	9.75	
9	7	3/4	8.51	
12	7	1/2	12.63	
10	7	1/2	9.75	
11	7	3/4	11.13	
11	7	3/4	11.13	
9	7	3/4	8.51	
8	7	3/4	7.40	
12	8	3/4	13.61	
average	9	6	3/4	
minimum	6	4	1/4	
maximum	12	8	1 1/4	
total				427.5 ft <sup>3</sup>

<b>Total Gross Log Volume</b>	<b>456.0 ft<sup>3</sup></b>
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**Appendix B-2**  
**Lodgepole Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>5</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
241	2.10	2.13	8232	ss		1/6	14.3	0.496
296	2.24	2.13	10811	ss		1/6	13.2	0.461
104	2.15	2.12	11465	ss		1/6	12.5	0.538
181	2.02	2.09	7451	ss		1/6	12.4	0.477
100	2.25	2.08	11133	ss		1/6	12.5	0.495
75	2.10	2.06	9951	1	xs	1/6	14.2	0.451
294	2.13	2.05	10361	ss		1/6	13.4	0.476
45	1.96	2.05	10371	ss		1/6	14.5	0.496
141	1.94	2.05	10420	2	shk	1/6	14.9	0.489
242	2.04	2.03	10049	1	xs	1/6	14.2	0.467
243	2.08	2.02	11182	ss		1/6	12.7	0.461
251	2.23	2.02	8984	2	w	1/6	12.8	0.471
46	1.99	1.98	8574	1	xs	1/6	14.7	0.463
107	1.83	1.98	9434	1	xs	1/6	12.9	0.435
60	1.98	1.98	9473	1	xs	1/6	14.3	0.428
274	1.93	1.96	9863	2	w	1/6	12.8	0.495
207	2.10	1.94	10205	2	w	1/6	13.3	0.468
47	1.78	1.92	9590	2	es	1/6	14.8	0.447
128	2.08	1.92	10586	ss		1/6	15.2	0.456
55	1.96	1.91	9004	1	xs	1/6	14.5	0.442
203	2.07	1.90	9229	1	xs	1/6	13.7	0.457
176	1.88	1.88	8867	1	ok	1/6	12.6	0.449
72	1.89	1.87	7510	1	xs	1/6	14.2	0.497
235	1.88	1.87	11582	ss		1/6	12.7	0.489
end of 2400Fb - 2.0E grade								
6	2.00	1.87	7744	3	w	1/6	14.4	0.499
167	1.96	1.86	9980	ss		1/6	14.1	0.436
299	1.83	1.86	8994	ss		1/6	12.7	0.425
246	1.93	1.86	10400	2	w	1/6	13.7	0.436
158	1.99	1.85	8838	ss		1/6	13.4	0.423
249	1.75	1.85	8721	ss		1/6	12.2	0.407
131	1.76	1.85	10059	1	xs	1/6	13.0	0.429
40	1.86	1.84	11113	ss		1/6	14.2	0.477
262	1.80	1.83	7539	1	xs	1/6	12.8	0.416
116	1.78	1.82	9551	ss		1/6	14.2	0.447
89	1.64	1.82	8369	1	xs	1/6	14.7	0.432
134	1.85	1.82	9912	2	w	1/6	14.5	0.461
173	1.98	1.81	9375	2	w	1/6	13.6	0.451
165	1.98	1.80	9834	2	w	1/6	13.0	0.430
140	1.76	1.80	7979	1	xs	1/6	14.6	0.425
138	2.06	1.79	9277	ss		1/6	14.2	0.462
277	1.70	1.79	9277	1	xs	1/6	13.1	0.400
37	1.62	1.79	8105	1	xs	1/6	14.2	0.442
30	1.78	1.79	9355	2	w	1/6	13.2	0.436

**Appendix B-2**  
**Lodgepole Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
95	1.66	1.79	7051	1	xs	1/6	14.2	0.428
152	1.98	1.79	9297	2	w	1/6	14.2	0.432
106	1.80	1.78	8701	2	w	1/6	11.9	0.414
192	1.80	1.78	9766	2	poc	1/6	12.8	0.460
285	1.82	1.77	8457	2	w	1/6	13.8	0.440
67	1.83	1.77	7949	1	xs	1/6	13.9	0.466
281	1.67	1.75	7617	1	xs	1/6	13.3	0.421
105	1.57	1.75	8105	1	xs	1/6	12.0	0.412
33	1.66	1.75	8535	1	xs	1/6	14.6	0.363
210	1.68	1.74	8213	1	xs	1/6	12.6	0.451
73	1.77	1.74	10850	3	w	1/6	15.3	0.526
220	1.73	1.73	8193	ss		1/6	13.0	0.415
258	1.71	1.72	6396	1	xs	1/6	13.2	0.393
155	1.76	1.72	9570	ss		1/6	13.7	0.428
end of 2100Fb - 1.8E grade								
49	1.90	1.72	7246	2	w	1/6	15.0	0.483
264	1.68	1.72	7910	1	xs	1/6	13.0	0.410
178	1.78	1.72	8770	1	xs	1/6	13.2	0.510
127	1.87	1.71	8047	2	w	1/6	14.6	0.440
199	1.78	1.71	7588	1	ok	1/6	12.7	0.420
102	1.74	1.70	8252	1	xs	1/6	12.9	0.465
20	1.76	1.70	8438	ss		1/6	14.9	0.463
44	1.82	1.70	9240	2	w	1/6	14.3	0.396
48	1.71	1.69	8008	2	hc	1/6	14.2	0.435
84	1.64	1.69	8281	2	w	1/6	13.8	0.379
214	1.63	1.69	9082	2	shk	1/6	13.3	0.402
4	1.74	1.68	8076	1	xs	1/6	14.1	0.431
259	1.67	1.68	6650	1	na	1/6	12.9	0.445
74	1.72	1.68	6309	1	xs	1/6	12.9	0.406
228	1.65	1.68	8135	1	xs	1/6	13.4	0.430
237	1.46	1.68	5205	1	xs	1/6	13.3	0.400
263	1.64	1.68	9297	ss		1/6	13.1	0.392
215	1.66	1.67	6846	1	xs	1/6	13.8	0.405
187	1.74	1.67	9219	1	xs	1/6	13.2	0.419
291	1.49	1.67	7998	1	xs	1/6	13.6	0.442
170	1.68	1.66	9307	1	xs	1/6	12.4	0.415
29	1.62	1.66	7344	1	xs	1/6	14.1	0.424
284	1.56	1.65	5664	1	xs	1/6	12.1	0.377
229	1.66	1.65	7920	ss		1/6	13.4	0.393
189	1.67	1.65	9375	ss		1/6	12.3	0.381
42	1.65	1.64	8711	1	xs	1/6	14.5	0.432
51	1.62	1.64	6475	1	xs	1/6	15.0	0.427
208	1.58	1.64	8477	2	w	1/6	12.2	0.430
257	1.48	1.64	9199	1	xs	1/6	12.7	0.390



**Appendix B-2**  
**Lodgepole Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
111	1.81	1.64	6660	1	xs	1/6	14.3	0.423
62	1.70	1.63	8633	ss		1/6	14.6	0.422
86	1.64	1.63	7217	1	xs	1/6	13.3	0.472
150	1.32	1.63	6758	1	xs	1/6	13.5	0.379
43	1.80	1.62	5879	1	xs	1/6	14.2	0.424
233	1.56	1.62	8584	2	dec	1/6	12.6	0.395
166	1.51	1.61	5830	1	xs	1/6	13.7	0.378
279	1.62	1.61	7705	1	xs	1/6	13.0	0.429
123	1.68	1.61	7979	1	xs	1/6	14.5	0.421
41	1.60	1.61	6963	1	xs	1/6	14.3	0.399
52	1.54	1.60	8467	2	w	1/6	12.6	0.427
129	1.56	1.60	6328	1	ok	1/6	14.1	0.398
271	1.58	1.60	9141	2	w	1/6	13.3	0.365
211	1.62	1.60	5986	1	xs	1/6	12.6	0.403
238	1.61	1.60	7559	ss		1/6	13.2	0.415
115	1.59	1.59	7100	1	xs	1/6	14.1	0.416
209	1.61	1.58	6768	2	w	1/6	11.4	0.401
53	1.70	1.58	7109	2	w	1/6	13.4	0.435
261	1.84	1.58	5049	1	ek	1/4	12.7	0.402
254	1.62	1.58	7988	1	xs	1/6	12.8	0.430
79	1.51	1.58	8506	1	xs	1/6	12.5	0.395
70	1.58	1.57	7256	1	xs	1/6	13.8	0.408
80	1.57	1.57	3965	1	xs	1/6	13.9	0.416
180	1.57	1.57	7451	1	xs	1/6	12.6	0.389
191	1.55	1.56	6836	ss		1/6	12.2	0.415
18	1.58	1.56	7959	1	xs	1/6	14.7	0.421
157	1.80	1.56	6152	2	hc	1/6	12.7	0.434
108	1.60	1.56	7969	1	xs	1/6	13.6	0.415
300	1.48	1.56	6035	1	xs	1/6	12.0	0.382
117	1.64	1.56	5557	1	xs	1/6	12.6	0.413
1	1.56	1.56	7891	2	w	1/6	11.6	0.380
286	1.58	1.55	7744	1	xs	1/6	12.8	0.367
200	1.49	1.55	6045	1	xs	1/6	12.9	0.412
88	1.44	1.55	6016	2	w	1/6	14.6	0.399
34	1.64	1.55	6494	3	w	1/6	14.5	0.413
132	1.66	1.54	8223	2	w	1/6	14.4	0.447
147	1.48	1.54	7109	1	xs	1/6	13.3	0.406
293	1.50	1.54	7422	2	w	1/6	12.8	0.355
164	1.59	1.54	6201	2	w	1/6	12.8	0.442
289	1.55	1.53	7715	1	xs	1/6	12.1	0.402
144	1.53	1.53	6885	1	xs	1/6	12.9	0.435
179	1.49	1.53	7246	1	xs	1/6	13.1	0.389
35	1.61	1.52	6162	1	xs	1/6	14.3	0.421
38	1.51	1.52	7061	2	w	1/6	14.2	0.387
77	1.54	1.52	5967	1	ek	1/4	14.7	0.410

**Appendix B-2**  
**Lodgepole Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
162	1.64	1.51	5264	2	w	1/6	12.6	0.418
292	1.43	1.51	7539	1	xs	1/6	13.0	0.409
83	1.53	1.51	6143	1	xs	1/4	14.8	0.405
59	1.66	1.51	6055	1	ek	1/4	14.7	0.414
172	1.52	1.51	5576	3	w	1/6	13.4	0.401
216	1.49	1.51	6602	1	xs	1/6	13.5	0.402
194	1.53	1.51	6689	2	ws	1/6	13.5	0.373
149	1.48	1.51	7344	1	poc	1/4	13.7	0.415
206	1.45	1.51	7822	1	xs	1/6	12.0	0.364
15	1.40	1.51	7314	1	xs	1/6	14.1	0.372
126	1.36	1.51	8867	1	xs	1/6	14.0	0.406
78	1.44	1.50	6494	1	xs	1/6	13.1	0.466
288	1.55	1.50	8965	ss		1/6	12.4	0.353
171	1.49	1.50	5615	1	xs	1/6	12.9	0.401
21	1.47	1.50	7783	1	xs	1/6	14.6	0.398
71	1.44	1.50	5957	1	xs	1/6	14.2	0.399
112	1.55	1.50	6572	1	xs	1/6	13.8	0.387
252	1.38	1.49	6904	ss		1/6	12.9	0.379
163	1.57	1.49	8682	ss		1/6	12.8	0.370
7	1.66	1.49	6582	3	w	1/6	14.9	0.409
182	1.41	1.49	7666	2	w	1/6	12.4	0.407
282	1.28	1.49	6738	1	xs	1/6	12.9	0.374
91	1.40	1.48	6523	1	xs	1/6	13.3	0.397
213	1.47	1.48	6279	ss		1/6	12.5	0.371
168	1.44	1.48	4668	1	ok	1/6	14.0	0.387
169	1.43	1.48	6377	1	xs	1/6	12.8	0.401
247	1.46	1.48	4746	2	slp	1/6	11.7	0.446
31	1.51	1.48	6182	1	xs	1/6	14.3	0.381
85	1.45	1.48	6611	1	xs	1/6	14.3	0.424
32	1.39	1.47	7236	ss		1/6	14.6	0.382
57	1.43	1.47	8164	2	es	1/6	14.4	0.424
146	1.44	1.47	5791	1	xs	1/6	13.8	0.365
143	1.43	1.47	7598	1	xs	1/6	12.8	0.426
110	1.44	1.47	5664	1	xs	1/6	13.3	0.421
148	1.47	1.47	6211	1	xs	1/6	13.5	0.382
9	1.57	1.46	4668	1	xs	1/6	13.7	0.414
217	1.39	1.46	6289	ss		1/6	12.8	0.367
121	1.53	1.46	5615	1	xs	1/6	14.1	0.413
177	1.42	1.46	7432	1	xs	1/6	12.8	0.377
202	1.46	1.46	7168	2	w	1/6	13.2	0.389
5	1.56	1.46	5791	2	xs	1/6	14.8	0.410
16	1.30	1.46	7773	1	xs	1/6	14.2	0.395
197	1.49	1.46	7549	1	xs	1/6	12.2	0.413
280	1.41	1.46	6387	1	xs	1/6	13.1	0.398
185	1.58	1.46	7119	2	w	1/6	13.1	0.484

**Appendix B-2**  
**Lodgepole Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
283	1.39	1.46	6357	1	xs	1/6	13.6	0.359
188	1.44	1.45	5918	1	xs	1/6	12.9	0.414
130	1.53	1.45	5498	1	xs	1/6	13.0	0.396
186	1.39	1.45	5576	1	xs	1/6	13.5	0.400
174	1.52	1.45	8242	ss		1/6	13.3	0.354
97	1.45	1.44	5938	1	xs	1/6	13.8	0.406
87	1.55	1.44	7441	2	w	1/4	14.4	0.431
219	1.42	1.44	6270	1	xs	1/6	12.5	0.401
159	1.43	1.43	6260	1	xs	1/6	13.2	0.375
109	1.45	1.43	6963	1	xs	1/6	14.2	0.407
27	1.38	1.42	8027	1	xs	1/6	13.0	0.355
50	1.27	1.42	5391	3	hc	1/6	14.8	0.407
139	1.42	1.42	5234	1	xs	1/6	14.3	0.395
198	1.37	1.42	8652	2	es	1/6	12.4	0.375
142	1.34	1.42	8800	1	xs	1/6	14.2	0.386
297	1.36	1.42	6465	1	xs	1/6	12.4	0.373
96	1.44	1.41	6064	1	xs	1/6	12.6	0.434
193	1.36	1.41	6650	1	xs	1/6	12.6	0.375
137	1.49	1.41	7129	1	xs	1/6	13.9	0.395
114	1.33	1.40	6484	2	bs	1/6	13.8	0.364
101	1.34	1.40	4424	1	xs	1/6	13.5	0.397
54	1.34	1.40	6631	1	xs	1/6	14.3	0.402
234	1.40	1.40	8105	1	xs	1/6	12.3	0.371
250	1.53	1.40	5166	1	xs	1/6	13.1	0.381
122	1.29	1.39	6953	2	w	1/6	14.2	0.415
196	1.46	1.39	6924	1	xs	1/6	11.3	0.399
133	1.35	1.39	7314	ss		1/6	13.9	0.367
248	1.34	1.39	6113	1	xs	1/6	12.1	0.373
265	1.42	1.39	5234	1	xs	1/6	13.0	0.415
190	1.28	1.39	7324	1	xs	1/6	12.9	0.348
56	1.60	1.39	6289	2	w	1/6	14.4	0.424
154	1.41	1.38	5459	3	w	1/6	14.2	0.396
93	1.32	1.38	5967	1	xs	1/6	13.1	0.389
153	1.62	1.38	4453	1	xs	1/6	14.0	0.397
12	1.35	1.38	5117	1	xs	1/6	14.6	0.360
218	1.29	1.38	6895	1	xs	1/6	12.2	0.357
125	1.31	1.38	6162	2	shk/ps	1/6	14.1	0.376
201	1.41	1.37	5527	1	ek	1/6	13.2	0.377
226	1.38	1.37	4736	1	xs	1/6	13.4	0.408
183	1.38	1.37	4072	1	xs	1/6	12.1	0.406
244	1.27	1.37	6133	1	xs	1/6	12.3	0.372
255	1.27	1.36	5547	1	xs	1/6	12.9	0.351
61	1.42	1.36	7871	1	xs	1/6	13.1	0.403
268	1.31	1.36	6221	1	xs	1/6	13.8	0.385
64	1.30	1.36	4238	2	w	1/6	14.8	0.371

**Appendix B-2**  
**Lodgepole Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
156	1.29	1.36	6445	3	hc	1/6	12.6	0.362
119	1.36	1.35	6523	1	xs	1/6	13.8	0.401
223	1.25	1.34	7666	1	xs	1/6	13.6	0.407
269	1.27	1.34	5518	1	xs	1/6	13.2	0.378
124	1.31	1.34	4668	1	xs	1/6	13.9	0.405
82	1.23	1.34	5654	1	xs	1/6	14.9	0.370
278	1.31	1.33	7139	1	xs	1/6	13.2	0.366
266	1.32	1.33	6934	1	xs	1/6	13.7	0.391
205	1.39	1.33	4063	1	xs	1/6	12.5	0.361
11	1.18	1.32	5645	1	xs	1/6	14.3	0.381
13	1.37	1.32	4727	3	w	1/6	12.4	0.360
272	1.30	1.32	5811	2	shk	1/6	13.5	0.415
8	1.39	1.31	5303	1	xs	1/6	14.5	0.354
175	1.27	1.31	5098	1	xs	1/6	12.9	0.353
63	1.33	1.31	3760	1	xs	1/6	14.5	0.392
76	1.21	1.31	5654	1	xs	1/6	14.5	0.391
298	1.34	1.31	5508	2	slp	1/4	12.9	0.390
99	1.25	1.30	6221	2	w	1/6	13.3	0.397
224	1.31	1.30	5723	ss		1/6	13.3	0.397
69	1.25	1.30	5186	1	xs	1/6	13.3	0.408
231	1.19	1.29	5625	1	xs	1/6	12.2	0.356
236	1.33	1.29	7480	3	w	1/6	13.4	0.354
273	1.33	1.28	5254	1	ek	1/4	12.6	0.380
end of 1650Fb - 1.5E grade								
195	1.24	1.28	4502	1	xs	1/6	12.0	0.378
184	1.29	1.28	6738	1	xs	1/6	12.1	0.363
239	1.25	1.28	4727	1	xs	1/6	12.4	0.372
301	1.16	1.27	7803	1	xs	1/6	12.0	0.373
90	1.17	1.27	6719	1	xs	1/6	14.3	0.387
161	1.26	1.27	4844	1	xs	1/6	12.1	0.385
145	1.35	1.27	3506	1	xs	1/6	13.4	0.343
65	1.27	1.26	5498	1	xs	1/6	13.0	0.406
98	1.32	1.26	6641	1	xs	1/6	13.6	0.382
19	1.30	1.26	5234	1	xs	1/6	13.2	0.379
253	1.16	1.26	5967	1	xs	1/6	12.4	0.383
118	1.18	1.25	5313	1	xs	1/6	12.6	0.374
256	1.26	1.25	5977	1	xs	1/6	13.2	0.404
160	1.22	1.25	5195	1	xs	1/6	12.5	0.355
260	1.20	1.25	5801	1	xs	1/6	12.1	0.392
287	1.14	1.25	5059	1	xs	1/6	12.2	0.394
267	1.10	1.24	6113	1	xs	1/6	12.8	0.403
39	1.18	1.24	4639	1	xs	1/6	12.8	0.368
222	1.11	1.22	5928	1	xs	1/6	12.3	0.384
81	1.21	1.19	4844	1	xs	1/6	13.4	0.360

**Appendix B-2**  
**Lodgepole Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
26	1.20	1.19	5791	1	xs	1/6	13.2	0.359
230	1.15	1.18	4863	1	xs	1/6	12.9	0.379
10	1.23	1.18	4023	1	xs	1/6	13.3	0.372
290	1.21	1.18	3848	1	xs	1/6	12.5	0.348
3	1.27	1.17	4619	1	xs	1/6	13.1	0.368
135	1.17	1.17	5127	1	xs	1/6	13.4	0.410
240	1.14	1.16	5283	1	xs	1/6	14.0	0.363
113	1.18	1.16	4473	1	xs	1/6	13.1	0.374
276	1.25	1.16	5957	1	xs	1/6	13.7	0.438
245	1.17	1.15	5342	1	xs	1/6	13.1	0.358
232	1.10	1.13	3818	1	xs	1/6	13.6	0.364
36	1.13	1.12	7451	1	xs	1/6	13.8	0.387
270	1.04	1.07	6465	1	xs	1/6	13.5	0.411
94	1.09	1.07	5156	1	xs	1/6	13.3	0.406
23	1.08	1.07	3984	1	xs	1/4	14.6	0.406
68	1.06	1.05	5654	1	xs	1/6	14.2	0.404
227	1.03	1.02	3350	1	xs	1/6	13.1	0.340
66	1.03	1.01	5566	1	xs	1/6	12.6	0.382
151	1.21	1.26	4570	2	ws	1/6	13.9	0.400
92	1.45	1.18	3730	2	xs	1/4	12.1	0.365
136	1.15	1.17	5283	2	w	1/3	14.5	0.332
22	1.27	1.09	4854	2	ek	1/3	13.7	0.387
103	1.09	1.07	4805	2	w	1/6	12.0	0.332
212	1.08	1.05	5332	2	w	1/6	12.6	0.363
17	1.05	0.90	4678	2	w	1/6	14.2	0.334
225	1.42	1.50	6387	2	xs	1/3	13.1	0.401
120	1.19	1.17	6445	3	w	1/6	13.5	0.385
302	1.96	1.93	10303	3	w	1/3	11.3	0.435
204	1.52	1.43	7646	3	xs	1/3	13.0	0.390
average	1.52	1.52	7013				13.4	0.406

**Key to Visual Characteristic Code**

(This is the characteristic which limited the board to its assigned grade category.)

dec decay	poc pitch pocket
ek edge knot	shk shake
es edge skip	slp slope of grain
hc honeycomb	w wane
na not recorded	ws white speck
ok other knot	xs cross section

## Appendix B-3

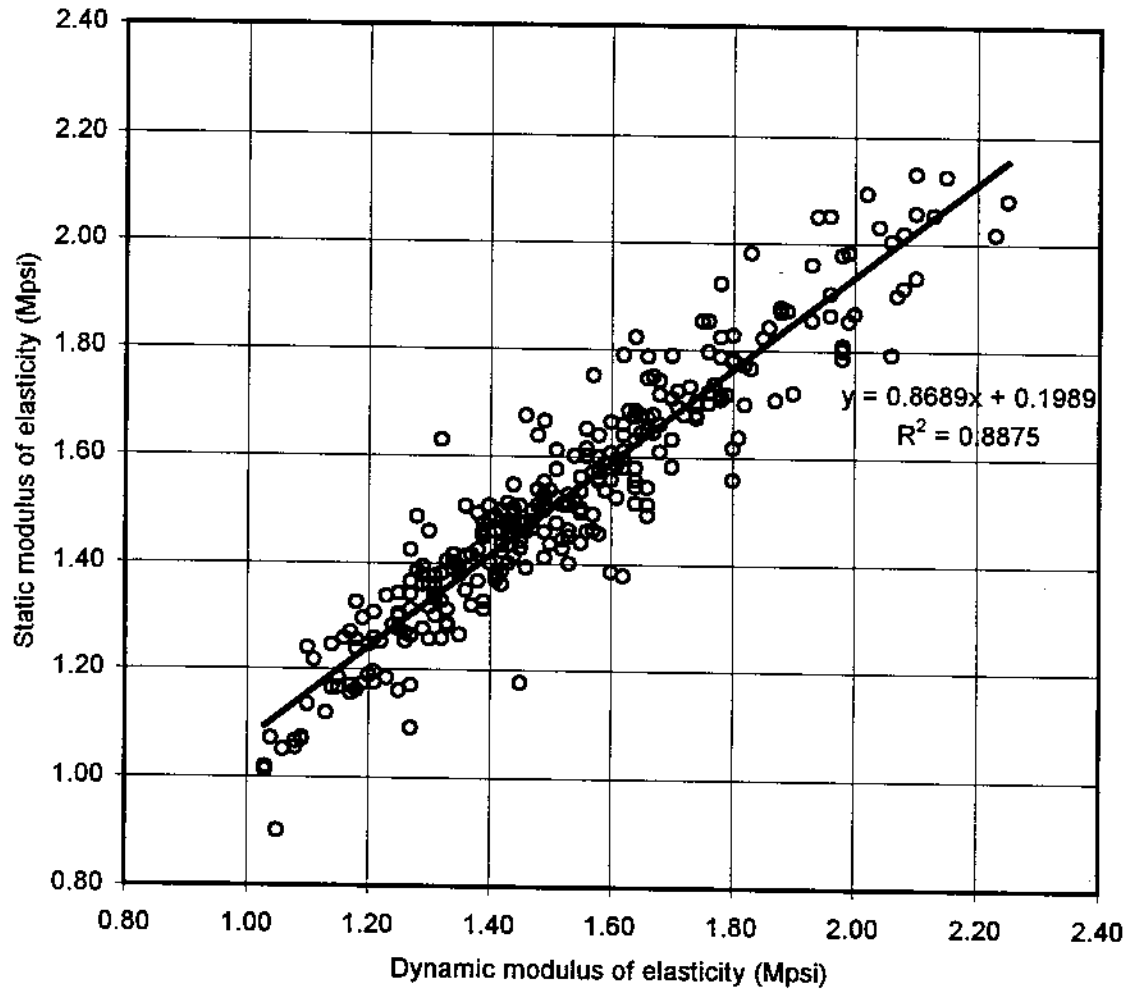


Figure 4. Static modulus of elasticity vs. dynamic modulus of elasticity for lodgepole pine sample.

## **Appendix C**

### **Ponderosa Pine Data**

Appendix C-1: Ponderosa Pine Log Data .....	48
Appendix C-2: Ponderosa Pine Visual Grades and Mechanical Properties.....	50
Appendix C-3: Static MOE vs. Dynamic MOE Regression.....	57

**Appendix C-1  
Ponderosa Pine Log Data**

(all logs are not included in this summary)

**12-foot nominal length**

	Large End Diameter (inches)	Small End Diameter (inches)	Largest Knot (inches)
	6	5	1
	8	5	2 1/4
	7	6	1 1/2
	8	6	2 1/4
	9	7	1 1/4
	11	8	2 3/4
	9	8	1
	12	9	1 1/4
	15	11	1 1/4
average	9	7	1 1/2
minimum	6	5	1
maximum	15	11	3

**24-foot nominal length**

	Large End Diameter (inches)	Small End Diameter (inches)	Largest Knot (inches)
	10	5	2
	9	5	2 1/4
	8	5	1 1/2
	10	5	1
	9	5	2 1/4
	9	5	1 1/2
	10	5	1 1/4
	11	5	1 1/2
	10	5	1
	8	5	1 1/2
	9	6	1 1/4
	8	6	1 1/4
	10	6	1 1/4
	11	6	1 1/4
	10	6	1
	11	6	1
	11	6	2 1/4
	8	6	1 1/4
	10	6	1
	10	6	1 1/4
	12	7	1 1/4
	10	7	2
	14	7	1
	14	7	2



**Appendix C-1  
Ponderosa Pine Log Data**

**24-foot nominal length**

	Large End Diameter (inches)	Small End Diameter (inches)	Largest Knot (inches)
	11	7	1 1/4
	10	7	1 3/4
	14	7	1 1/2
	12	7	1 1/2
	13	8	2
	14	8	1 1/4
	12	8	1 1/4
	11	8	1 3/4
	12	8	2 1/2
	14	8	1 3/4
	12	8	2
	10	8	1 1/2
	16	9	2 1/2
	17	9	1 1/2
	15	9	1 1/4
	15	9	1 1/2
	15	9	1 3/4
	15	10	2
	13	10	1 1/4
	16	10	2
	15	11	1 1/2
	16	11	1 1/2
average	12	7	1 1/2
minimum	8	5	1
maximum	17	11	2 1/2

**Appendix C-2**  
**Ponderosa Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
67	1.20	1.20	5000		ss	1/6	11.3	0.367
101	1.16	1.12	5625	1	ek	1/4	12.1	0.388
56	1.04	1.06	5205	1	ek	1/3	9.2	0.346
221	1.10	1.02	4033	1	ek	1/4	10.7	0.378
270	1.00	1.01	5596	1	ek	1/3	11.6	0.350
198	1.04	0.98	5781	1	ek	1/4	11.8	0.314
232	0.97	0.85	3340	1	ek	1/4	11.1	0.358
290	0.80	NA	NA	1	ok	1/4	8.3	0.347
268	1.33	1.36	6709	1	ok	1/4	11.2	0.412
230	1.23	1.24	4824	1	ok	1/6	10.4	0.367
177	1.22	1.17	3789	1	ok	1/6	10.1	0.335
78	1.17	1.16	8584	1	ok	1/4	10.2	0.386
34	0.99	1.13	7578	1	ok	1/6	11.7	0.360
8	1.11	1.07	3477	1	ok	1/6	9.0	0.334
52	1.06	1.05	5586	1	ok	1/4	10.9	0.331
126	1.20	1.04	4414	1	ok	1/4	9.1	0.329
240	1.16	1.04	5029	1	ok	1/6	10.9	0.406
151	1.11	1.03	5928	1	ok	1/6	10.4	0.330
74	1.11	1.02	4678	1	ok	1/4	11.1	0.371
6	1.05	1.00	4561	1	ok	1/6	11.3	0.328
206	0.94	1.00	6084	1	ok	1/4	12.6	0.352
141	1.07	0.98	2705	1	ok	1/4	11.0	0.323
47	0.97	0.95	4287	1	ok	1/3	11.1	0.366
176	0.99	0.94	4629	1	ok	1/4	9.0	0.390
98	0.98	0.94	3330	1	ok	1/4	10.7	0.345
241	0.88	0.92	5566	1	ok	1/6	10.4	0.339
25	0.87	0.88	5508	1	ok	1/4	10.7	0.349
129	0.96	0.88	3027	1	ok	1/4	12.7	0.353
199	0.98	0.86	2754	1	ok	1/4	11.6	0.298
103	0.92	0.85	3535	1	ok	1/4	12.1	0.297
159	0.88	0.84	4268	1	ok	1/6	13.4	0.318
61	0.89	0.84	3369	1	ok	1/4	10.6	0.358
30	0.80	0.83	4131	1	ok	1/4	10.5	0.414
89	0.83	0.82	3604	1	ok	1/4	11.5	0.312
153	0.79	0.81	3516	1	ok	1/4	12.3	0.309
4	0.86	0.79	5332	1	ok	1/4	11.0	0.347
92	0.79	0.77	5760	1	ok	1/6	12.6	0.425
86	0.82	0.76	3428	1	ok	1/4	11.1	0.373
66	0.84	0.73	2607	1	ok	1/4	11.0	0.317
277	1.12	NA	NA	1	xs	1/4	8.3	0.346
288	0.98	NA	NA	1	xs	1/3	9.3	0.349
261	1.37	1.35	5527	1	xs	1/6	11.0	0.379
167	1.28	1.30	7090	1	xs	1/6	13.0	0.373
81	1.28	1.28	5723	1	xs	1/4	10.8	0.370
5	1.25	1.24	3506	1	xs	1/4	11.1	0.383

**Appendix C-2**  
**Ponderosa Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
212	1.27	1.19	3760	1	xs	1/3	11.8	0.383
107	1.21	1.16	5693	1	xs	1/4	12.6	0.429
205	1.14	1.13	4521	1	xs	1/6	11.9	0.374
164	1.15	1.13	5684	1	xs	1/6	10.6	0.314
247	1.01	0.97	4639	1	xs	1/6	11.6	0.405
170	1.01	0.93	4932	1	xs	1/6	9.9	0.357
189	0.88	0.92	3193	1	xs	1/4	10.2	0.379
65	0.89	0.91	4600	1	xs	1/4	11.5	0.376
166	0.91	0.77	3887	1	xs	1/3	13.0	0.372
77	0.80	0.76	3135	1	xs	1/4	11.3	0.332
121	0.75	0.75	4590	1	xs	1/6	12.5	0.361
26	0.70	0.74	3750	1	xs	1/4	11.3	0.358
33	0.69	0.73	4014	1	xs	1/4	11.5	0.409
27	0.84	0.73	1855	1	xs	1/4	11.4	0.308
119	0.70	0.73	3135	1	xs	1/4	13.0	0.340
238	0.73	0.73	2725	1	xs	1/6	10.7	0.280
2	NA	0.72	3301	1	xs	1/6	10.4	0.411
197	0.84	0.71	3115	1	xs	1/6	12.0	0.309
31	0.80	0.71	3887	1	xs	1/4	10.8	0.348
134	0.67	0.70	5371	1	xs	1/6	11.9	0.382
257	0.77	0.69	2832	1	xs	1/6	12.0	0.337
18	0.64	0.69	2021	1	xs	1/4	11.0	0.318
10	0.66	0.66	2920	1	xs	1/6	10.2	0.388
190	0.60	0.64	3535	1	xs	1/4	10.6	0.407
102	0.61	0.63	3369	1	xs	1/4	12.1	0.371
19	0.59	0.58	4072	1	xs	1/6	11.6	0.349
179	1.02	0.94	3369	1(10)	ek	1/4	11.8	0.366
130	0.49	0.50	2832	1(10)	ek	1/4	11.7	0.395
284	1.08	NA	NA	1(10)	ok	1/4	11.0	0.318
42	1.17	1.30	7676	1(10)	ok	1/6	11.0	0.427
204	1.35	1.21	7031	1(10)	ok	1/4	11.0	0.385
60	1.14	1.16	6064	1(10)	ok	1/6	10.8	0.361
188	1.03	0.92	6133	1(10)	ok	1/4	10.6	0.351
12	0.71	0.75	5049	1(10)	ok	1/4	10.8	0.365
245	1.00	1.08	4844	1(10)	xs	1/4	11.7	0.348
23	0.94	0.92	4443	1(10)	xs	1/4	10.6	0.339
132	0.90	0.80	3203	1(10)	xs	1/4	13.2	0.333
91	0.81	0.79	3984	1(10)		1/6	10.9	0.336
186	0.64	0.69	2305	2		1/6	11.1	0.301
235	0.75	0.72	1934	2		1/3	11.8	0.335
286	1.15	NA	NA	2	ek	1/3	11.1	0.345
148	1.30	1.23	5107	2	ek	1/3	11.0	0.348
266	1.13	1.21	6455	2	ek	1/3	12.0	0.354
265	1.13	1.10	5723	2	ek	1/3	12.0	0.373
138	1.18	1.03	3955	2	ek	1/3	11.0	0.325

**Appendix C-2**  
**Ponderosa Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
15	1.07	0.99	2402	2	ek	1/3	9.5	0.310
273	0.95	0.99	6260	2	ek	1/3	11.6	0.356
63	0.96	0.97	4717	2	ek	1/3	11.6	0.398
43	1.01	0.96	6338	2	ek	1/4	11.4	0.386
237	1.02	0.95	4766	2	ek	1/3	11.4	0.356
225	0.79	0.85	6182	2	ek	1/4	11.7	0.349
271	0.87	0.81	4980	2	ek	1/3	11.1	0.320
203	0.90	0.81	3193	2	ek	1/4	10.3	0.334
104	0.86	0.80	3428	2	ek	1/3	11.9	0.303
135	0.81	0.76	3525	2	ek	1/3	11.0	0.370
100	0.74	0.70	4492	2	ek	1/3	11.9	0.376
269	0.70	0.70	2129	2	ek	1/3	11.4	0.302
264	0.80	0.67	3408	2	ek	1/3	11.7	0.341
32	0.58	0.53	4120	2	ek	1/3	11.1	0.368
272	0.98	0.96	4473	2	na	1/3	10.9	0.342
275	1.11	NA	NA	2	ok	1/4	10.2	0.370
293	0.82	NA	NA	2	ok	1/4	9.5	0.310
226	1.43	1.47	9668	2	ok	1/3	10.1	0.363
258	1.15	1.22	6484	2	ok	1/6	10.6	0.357
202	1.09	1.16	7861	2	ok	1/4	8.8	0.379
224	1.27	1.16	4834	2	ok	1/3	11.8	0.399
181	1.14	1.12	5791	2	ok	1/4	11.9	0.356
156	1.14	1.05	3125	2	ok	1/6	12.0	0.330
213	1.08	1.03	3896	2	ok	1/4	9.8	0.331
116	1.00	1.03	4551	2	ok	1/3	12.6	0.336
73	1.04	1.03	3887	2	ok	1/3	10.6	0.344
136	1.04	1.02	3994	2	ok	1/4	10.7	0.426
210	1.07	1.02	5859	2	ok	1/3	12.4	0.375
174	1.07	1.00	3408	2	ok	1/4	10.1	0.336
182	1.05	0.98	4902	2	ok	1/3	10.0	0.305
115	1.03	0.98	3496	2	ok	1/6	12.1	0.351
228	1.02	0.97	4131	2	ok	1/4	9.5	0.350
154	0.99	0.96	4287	2	ok	1/6	13.1	0.340
249	0.98	0.96	2754	2	ok	1/4	9.6	0.298
9	1.01	0.96	6133	2	ok	1/3	10.6	0.348
59	0.90	0.93	3516	2	ok	1/3	10.6	0.342
88	0.91	0.90	5488	2	ok	1/4	11.7	0.341
263	0.89	0.90	4736	2	ok	1/3	11.9	0.449
20	0.90	0.90	3389	2	ok	1/4	11.0	0.380
137	0.83	0.89	3291	2	ok	1/3	10.0	0.373
187	0.85	0.89	6440	2	ok	1/3	11.5	0.355
3	1.08	0.89	3906	2	ok	1/3	11.3	0.387
71	1.05	0.88	4287	2	ok	1/3	10.6	0.365
82	0.94	0.87	3291	2	ok	1/4	9.8	0.306
68	0.94	0.87	3125	2	ok	1/4	10.0	0.325

**Appendix C-2**  
**Ponderosa Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
105	0.93	0.85	4551	2	ok	1/3	10.5	0.298
84	0.86	0.84	4473	2	ok	1/4	10.0	0.318
58	0.84	0.82	3076	2	ok	1/3	10.7	0.311
28	0.83	0.80	5215	2	ok	1/3	11.1	0.359
46	0.78	0.77	5352	2	ok	1/4	11.6	0.341
41	0.95	0.76	2441	2	ok	1/3	9.9	0.375
124	0.84	0.75	2354	2	ok	1/3	10.5	0.322
251	0.62	0.69	4297	2	ok	1/4	12.0	0.345
140	0.78	0.67	4053	2	ok	1/3	13.1	0.350
278	1.28	NA	NA	2	w	1/6	9.4	0.354
106	1.28	1.20	4521	2	w	1/6	12.5	0.435
152	1.24	1.12	5332	2	w	1/4	11.1	0.408
49	1.02	1.08	5137	2	w	1/4	11.0	0.320
35	1.06	1.08	5127	2	w	1/3	10.9	0.336
178	0.95	1.02	5781	2	w	1/4	10.3	0.339
122	0.98	1.01	5479	2	w	1/3	8.6	0.333
231	0.98	0.98	4150	2	w	1/6	11.4	0.385
194	1.03	0.96	3877	2	w	1/3	11.9	0.322
128	1.10	0.92	3721	2	w	1/3	11.5	0.359
165	0.96	0.88	5977	2	w	1/6	9.5	0.345
72	0.91	0.85	4092	2	w	1/6	10.6	0.390
200	0.57	0.52	3262	2	w	1/4	10.7	0.358
125	0.81	0.82	2988	2	wrp	1/4	9.4	0.316
45	0.67	0.74	2695	2	wrp	1/4	9.6	0.356
147	0.65	0.73	6240	2	wrp	1/6	12.8	0.407
36	0.76	0.72	2197	2	wrp	1/3	11.3	0.334
7	0.72	0.71	2988	2	wrp	1/4	10.8	0.353
44	0.70	0.70	2500	2	wrp	1/3	10.7	0.342
80	0.64	0.67	3184	2	wrp	1/4	10.2	0.296
1	0.62	0.65	4033	2	wrp	1/3	10.7	0.398
96	0.64	0.64	3496	2	wrp	1/3	10.8	0.372
171	0.55	0.55	2100	2	wrp	1/4	10.1	0.318
274	0.98	NA	NA	2	xs	1/6	12.0	0.341
276	0.74	NA	NA	2	xs	1/3	9.6	0.293
279	0.71	NA	NA	2	xs	1/4	9.5	0.326
280	0.72	NA	NA	2	xs	1/4	10.4	0.349
281	0.74	NA	NA	2	xs	1/4	8.4	0.411
283	1.12	NA	NA	2	xs	1/3	10.0	0.342
285	0.88	NA	NA	2	xs	1/3	9.3	0.393
287	0.68	NA	NA	2	xs	1/4	10.6	0.314
289	0.71	NA	NA	2	xs	1/4	9.8	0.328
291	0.94	NA	NA	2	xs	1/4	8.6	0.322
294	0.71	NA	NA	2	xs	1/4	10.0	0.382
155	1.48	1.48	5840	2	xs	1/4	12.5	0.398
207	1.41	1.41	6748	2	xs	1/4	12.4	0.375

**Appendix C-2**  
**Ponderosa Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
208	1.07	1.18	4814	2	xs	1/6	12.1	0.349
262	1.06	1.10	4404	2	xs	1/4	11.0	0.393
244	1.07	1.06	6025	2	xs	1/6	11.4	0.349
191	1.03	1.05	5186	2	xs	1/4	10.8	0.362
252	1.12	1.04	4482	2	xs	1/3	11.4	0.367
112	0.90	1.03	3799	2	xs	1/3	10.5	0.318
11	1.08	1.02	3545	2	xs	1/4	11.3	0.359
37	0.98	1.02	5391	2	xs	1/6	10.7	0.357
220	0.99	1.01	6953	2	xs	1/4	10.5	0.391
29	0.97	0.97	3838	2	xs	1/4	10.8	0.319
76	0.88	0.96	5469	2	xs	1/4	11.8	0.380
259	1.04	0.95	2559	2	xs	1/4	11.3	0.347
108	0.86	0.95	7000	2	xs	1/6	11.2	0.398
87	0.82	0.93	4346	2	xs	1/3	10.5	0.400
173	0.95	0.92	3838	2	xs	1/6	11.1	0.359
209	0.85	0.92	4873	2	xs	1/4	11.5	0.354
144	1.05	0.91	3545	2	xs	1/4	13.4	0.356
14	0.97	0.91	3711	2	xs	1/4	11.0	0.332
185	0.90	0.90	2383	2	xs	1/4	11.9	0.340
50	0.88	0.88	2822	2	xs	1/4	10.6	0.321
246	0.76	0.87	4814	2	xs	1/3	10.1	0.360
95	0.77	0.86	3984	2	xs	1/3	11.8	0.330
69	0.75	0.86	2773	2	xs	1/4	10.0	0.354
192	0.87	0.85	2676	2	xs	1/4	10.6	0.364
243	0.82	0.84	3545	2	xs	1/4	9.2	0.351
214	0.93	0.84	2100	2	xs	1/4	8.3	0.418
234	0.77	0.83	3652	2	xs	1/6	11.0	0.366
242	0.83	0.83	1963	2	xs	1/3	10.5	0.333
229	0.84	0.82	2656	2	xs	1/3	8.9	0.313
57	0.80	0.82	4951	2	xs	1/4	11.7	0.378
222	0.88	0.81	2617	2	xs	1/4	11.2	0.328
219	0.86	0.80	1738	2	xs	1/4	11.2	0.296
131	0.82	0.79	3691	2	xs	1/4	12.0	0.363
139	0.84	0.79	6080	2	xs	1/3	11.9	0.359
38	0.81	0.79	2334	2	xs	1/3	11.1	0.334
85	0.70	0.79	3145	2	xs	1/3	8.6	0.325
196	0.76	0.78	2891	2	xs	1/4	12.5	0.337
255	0.80	0.78	2695	2	xs	1/4	9.0	0.301
17	0.73	0.78	2627	2	xs	1/3	9.2	0.333
117	0.81	0.78	3262	2	xs	1/3	12.0	0.329
53	0.73	0.77	3086	2	xs	1/3	10.4	0.347
150	0.77	0.77	2354	2	xs	1/3	10.3	0.309
161	0.76	0.75	3848	2	xs	1/4	10.7	0.365
253	0.78	0.75	3477	2	xs	1/4	10.8	0.316
217	0.88	0.74	2832	2	xs	1/4	9.3	0.320

**Appendix C-2**  
**Ponderosa Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
118	0.74	0.73	3232	2	xs	1/4	12.4	0.421
16	0.76	0.73	2441	2	xs	1/3	10.9	0.350
211	0.72	0.72	4678	2	xs	1/4	11.9	0.340
250	0.65	0.72	4453	2	xs	1/4	10.0	0.367
215	0.85	0.71	2275	2	xs	1/4	9.2	0.316
233	0.77	0.70	2070	2	xs	1/3	11.4	0.274
142	0.73	0.69	2080	2	xs	1/3	12.5	0.342
114	0.69	0.69	2441	2	xs	1/4	12.1	0.321
172	0.69	0.69	2568	2	xs	1/4	11.9	0.341
39	0.70	0.68	1416	2	xs	1/3	10.7	0.305
127	0.63	0.66	2578	2	xs	1/4	12.7	0.321
75	0.67	0.66	2842	2	xs	1/6	11.9	0.351
97	0.69	0.65	4521	2	xs	1/3	10.8	0.398
55	0.64	0.65	2871	2	xs	1/4	11.2	0.367
51	0.71	0.64	1475	2	xs	1/3	9.3	0.312
146	0.66	0.64	3936	2	xs	1/4	13.2	0.357
195	0.62	0.64	2432	2	xs	1/4	11.6	0.319
120	0.81	0.64	1660	2	xs	1/4	13.1	0.324
113	0.67	0.63	3135	2	xs	1/3	11.4	0.412
175	0.59	0.62	3740	2	xs	1/4	10.6	0.334
168	0.69	0.62	2900	2	xs	1/4	12.8	0.354
99	0.72	0.62	1689	2	xs	1/3	10.1	0.323
94	0.62	0.62	3682	2	xs	1/4	12.4	0.355
158	0.60	0.60	2441	2	xs	1/4	12.6	0.298
239	0.70	0.60	1240	2	xs	1/3	10.2	0.386
133	0.65	0.58	4141	2	xs	1/4	13.4	0.384
54	0.60	0.57	2900	2	xs	1/4	10.6	0.436
83	0.69	0.54	2061	2	xs	1/3	10.6	0.347
143	0.59	0.52	2158	2	xs	1/3	13.3	0.404
223	0.51	0.49	3623	2	xs	1/4	11.1	0.445
254	0.74	0.77	4521	2		1/4	11.4	0.335
48	0.96	0.97	4346	2(10)	ek	1/3	11.2	0.334
162	1.34	1.25	5850	2(10)	ok	1/4	10.4	0.316
218	1.15	0.99	3301	2(10)	ok	1/6	11.4	0.324
216	1.08	0.98	2559	2(10)	ok	1/4	9.9	0.344
13	0.94	0.90	4092	2(10)	ok	1/4	10.4	0.328
149	0.87	0.90	2598	2(10)	ok	1/4	10.0	0.469
79	0.83	0.79	3164	2(10)	ok	1/3	10.9	0.301
123	0.60	0.63	2285	2(10)	ok	1/3	10.9	0.298
267	1.33	1.24	5654	2(10)	w	1/4	11.8	0.379
109	1.07	1.14	4922	2(10)	w	1/3	10.5	0.328
24	0.87	0.87	5186	2(10)	w	1/6	9.4	0.341
70	0.93	0.84	3057	2(10)	w	1/4	10.5	0.336
201	0.93	0.87	5146	2(10)	wrp	1/4	9.4	0.377
22	0.64	0.69	4170	2(10)	wrp	1/4	11.0	0.401

**Appendix C-2**  
**Ponderosa Pine Visual Grades and Mechanical Properties**

Specimen Number	Dynamic MOE (10 <sup>6</sup> psi)	Static MOE (10 <sup>6</sup> psi)	MOR (psi)	Visual Grade (SLF)	Visual Charact. Code	Maximum Knot Size (ratio)	Moisture Content (%)	Specific Gravity
295	NA	NA	NA	2(10)	xs	1/3	11.0	0.302
110	0.76	0.83	4287	2(10)	xs	1/4	9.9	0.308
93	0.77	0.80	2539	2(10)	xs	1/3	11.4	0.321
21	0.69	0.68	2188	2(10)	xs	1/3	11.2	0.291
236	0.69	0.60	2900	2(10)	xs	1/4	10.9	0.307
90	0.72	0.71	4541	2(10)		1/4	11.2	0.403
292	0.96	NA	NA	3	ek	1/3	10.5	0.378
248	0.77	0.74	2432	3	ek	1/3	10.3	0.383
111	1.14	1.04	4414	3	es	1/6	10.5	0.378
260	0.82	0.69	1748	3	md	1/4	11.7	0.295
40	1.30	1.18	4375	3	ok	1/6	11.2	0.417
160	1.00	0.87	2412	3	ok	1/4	12.1	0.359
157	0.87	0.80	2363	3	ok	1/3	12.6	0.317
163	1.12	1.10	5137	3	w	1/3	10.2	0.389
282	0.64	NA	NA	3	xs	1/3	10.8	0.342
169	0.83	0.88	4199	3	xs	1/4	12.1	0.391
145	0.89	0.86	4277	3	xs	1/3	13.0	0.307
193	0.80	0.81	4834	3	xs	1/3	12.4	0.350
227	0.75	0.75	2559	3	xs	1/3	8.6	0.346
180	0.65	0.63	2236	3	xs	1/3	11.4	0.369
184	0.53	0.45	1992	3	xs	1/3	11.8	0.349
62	0.45	0.44	2432	3	xs	1/3	11.5	0.560
64	0.69	NA	NA	3(10)	w	1/4	11.6	0.328
183	1.05	0.97	5520	3(10)	w	1/4	12.1	0.333
256	0.97	0.91	3945	3(10)	w	1/6	11.8	0.325
average	0.90	0.87	4024				11.0	0.352

Note: Boards that were pencil trimmed to 10' are indicated by a "(10)" after the visual grade. These boards were tested as 12' pieces.

**Key to Visual Characteristic Code**

(This is the characteristic which limited the board to its assigned grade category.)

ek edge knot  
 es edge skip  
 md machine damage  
 na not recorded  
 ok other knot  
 w wane  
 wrp warp  
 xs cross section



## Appendix C-3

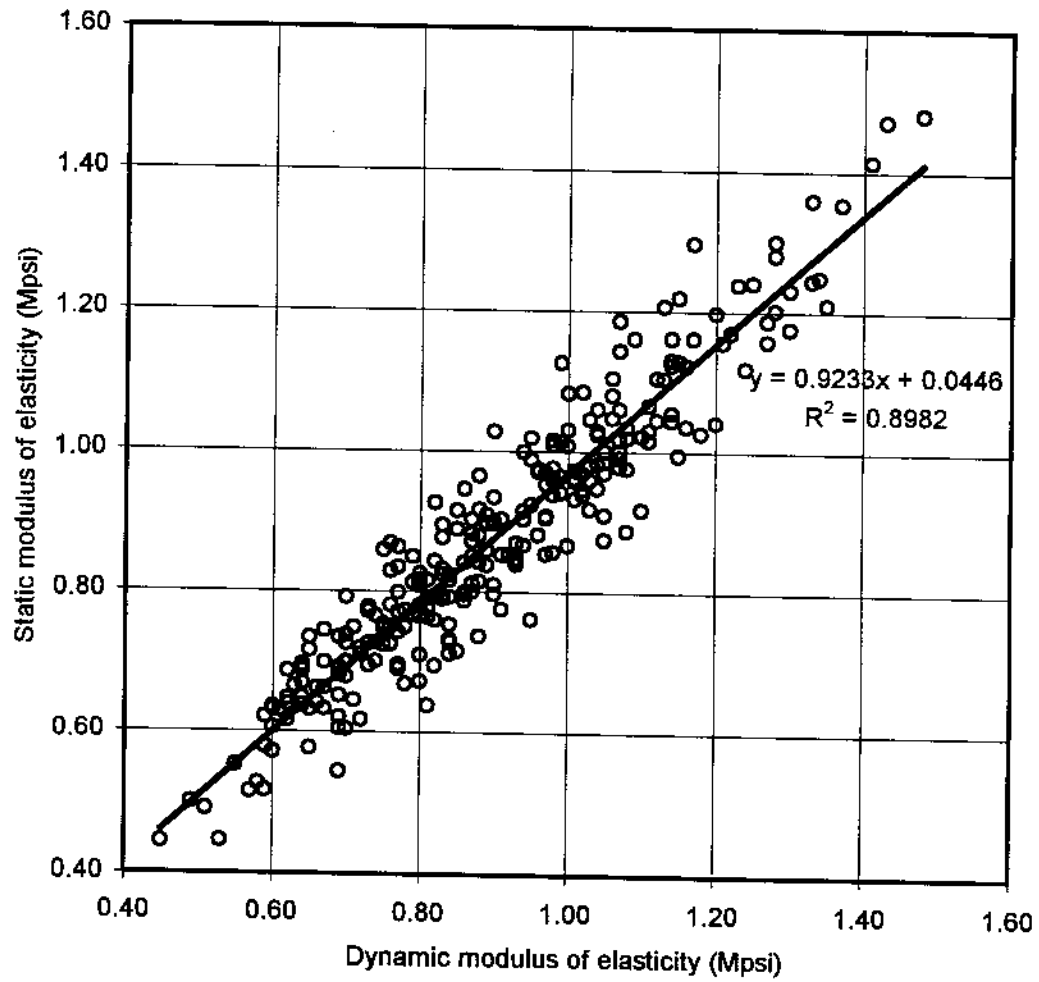


Figure 5. Static modulus of elasticity vs. dynamic modulus of elasticity for ponderosa pine sample.

## Appendix D

### Formulas

Modulus of elasticity (apparent) (MOE):

$$\text{MOE} = [(P_2 - P_1) \div (x_2 - x_1)] * [(L^3) \div (4.7bh^3)]$$

Where:

$(P_2 - P_1) \div (x_2 - x_1)$  = slope of deflection vs. force curve below proportional limit

L = span (73.5 inches)

b = width of 2x4 (1.5 inches)

h = height of 2x4 (3.5 inches)

Modulus of rupture (MOR):

$$\text{MOR} = (PL) \div (bh^2)$$

Where:

P = maximum compressive load (lbf)

L = span (73.5 inches)

b = width of 2x4 (1.5 inches)

h = height of 2x4 (3.5 inches)

Specific Gravity ( $SG_a$ ) adjusted to 12 percent moisture content:

$$SG_a = SG \div [1 + SG(0.009)(MC - 12)]$$

Where:

SG = unadjusted specific gravity

MC = moisture content (%)