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MSR Lumber Grade Recovery of Post Mountain Pine Beetle Wood

Conroy Lum

Mountain Pine Beetle Initiative
Working Paper 2005–21

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Abstract

A sample of mountain pine beetle (MPB) attacked wood from a drying study was tested to estimate the recovery of typical grades of machine stress rated (MSR) lumber. The MSR lumber recovery was simulated from the test results and visual quality of 1536 pieces of lodgepole pine. Each piece was visually graded and tested for edgewise-bending strength, edgewise-bending modulus of elasticity, and modulus of elasticity in transverse vibration. The amount of bluestain covering each piece was also noted.

Results from three common MSR lumber grade combinations (2400f-2.0E/2100f-1.8E/1650f-1.5E, 2100f-1.8E/1650f-1.5E, and 1650f-1.5E) are presented. Although the sample represents only the lumber from one mill at a point in time, the results support previous findings that the presence of bluestain has no impact on the mechanical properties of lumber.

Keywords: machine stress rated lumber, mountain pine beetle, lodgepole pine, lumber grade recovery, bending test, mechanical properties, bluestain

Résumé

Des tests ont été effectués sur un échantillon de bois attaqué par le dendroctone du pin et envoyé au séchage pour estimer le taux de récupération de la valeur du bois classé par contrainte mécanique (MSR). L'amélioration de la qualité du bois MSR a été simulée à partir du résultat des tests et de la qualité visuelle de 1 536 pièces de pins de Murray. Chaque pièce a été classée visuellement et testée pour déterminer sa résistance à la flexion, son module d'élasticité en flexion et son module d'élasticité transversal. Le taux de bleuissement affectant chaque pièce a également été consigné.

L'étude donne en outre les résultats de trois combinaisons de classification MSR communément utilisées (2400f-2.0E/2100f-1.8E/1650f-1.5E, 2100f-1.8E/1650f-1.5E et 1650f-1.5E). Même si l'échantillon utilisé est représentatif d'une seule usine à un moment précis dans le temps, les résultats obtenus confirment les conclusions antérieures voulant que la présence de bleuissements n'affecte pas les propriétés mécaniques du bois.

Mots clés : bois classé par contrainte mécanique, dendroctone du pin, pin de Murray, amélioration du bois classé par contrainte mécanique, test de courbure, propriétés mécaniques, bleuissement.

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1 Introduction

The mountain pine beetle (MPB) infestation has reached epidemic proportions in most of the central interior regions of British Columbia. The affected area now covers 8.0 million hectares representing an estimated timber value of $3.2 billion (Natural Resources Canada, 2005). Although mills will be producing more lumber due to the short-term increase in annual allowable cut of infested lodgepole pine inventory, benefits can only be realized if the increase in production is coupled with research and development related to processing strategies and new markets are developed (Ferguson, 2003).

The volume of lodgepole pine stands affected by the mountain pine beetle that are available for conversion to wood products is expected to continue to grow in the near future. In addition to increased volumes of bluestained wood, it is anticipated that the proportions of logs from dead trees that have reached the red and grey attack stages will increase.

In western Canada, the predominant species that appears in grades of Spruce-Pine-Fir (SPF) machine graded lumber is lodgepole pine. The machine grading process, in particular the system commonly used in North America, is designed to adapt to changes in the wood resource. Under this system, each production facility is required to establish the grading machine settings necessary such that the graded lumber, when sampled and tested in accordance with an approved product standard, meets the specifications for the grade. As to the impact of post-MPB wood on machine grading, there is concern post-MPB wood might not possess the same mechanical properties as normal wood. Furthermore, there is concern that new techniques to improve the drying of post-MPB wood could also inadvertently affect the mechanical properties (i.e., strength and stiffness) of lumber. Because the North American machine stress rated (MSR) system is designed to adapt to resource changes, reductions in mechanical properties, if any, would result in reduced MSR lumber recovery from post-MPB wood as compared to normal wood.

In this study, the MSR lumber recovery from a sample of post-MPB wood from each of three moisture content sorts from one MSR lumber mill was estimated. The information provides insight into the variations in MSR lumber recovery to be expected when processing post-MPB wood. The information could also serve as a useful baseline for comparing the effects of processing grey and red attack stands of MPB wood.

2 Materials and Methods

2.1 Test Sample

2.1.1 Source of Test Sample and Sample Selection

The test sample was from a millrun of lodgepole pine logs representative of recently killed stands of mountain pine beetle attacked wood (i.e., green attack). The lodgepole pine lumber sample was originally collected to evaluate the efficacy of different drying treatments on three moisture content sorts from an MSR lumber mill (Oliveira et al., 2005). Because the sample was collected at only one mill at one point in time, the results may not be representative of the entire growth region affected by the MPB.

In the drying studies, equal numbers of 16 ft. lodgepole pine lumber were randomly selected from each of three moisture sorts. Details of the samples and the drying treatments are given in Oliveira et al. (2005). Under that study, the specimens were each cut in half into 8 ft lengths and numbered as follows:

Table 1: Description of Drying Treatments

Treatment Number	Treatment Type
1	Conservative schedule
2	1 week air-dry + heat treatment schedule
3	3 week air-dry + heat treatment schedule

2.1.2 Sample Preparation and Visual Inspection

Only those pieces that exceeded the requirements of the "No. 2" Structural Light Framing grade were selected for the MSR recovery study.[1] In preparation for assessing the sample in accordance with the National Lumber Grades Authority (NLGA) SPS 2 for Machine Graded Lumber (NLGA 2003), the Visual Quality Level (VQL) of each piece was noted and the Maximum Strength Reducing Characteristic (MSRC) identified. The VQL code noted (Table 2) corresponds to the levels typically used in North American MSR lumber product standards.

Table 2: VQL or Strength-reducing edge characteristic limits for typical MSR grades

Fraction of Cross-section Displaced by the Edge Characteristic	Typical MSR Grades	VQL Code
$^{1}/_{2}$	Below 950f-1.0E	2
$^{1}/_{3}$	1200f-1.2E to 1450f-1.3E	3
$^{1}/_{4}$	1500f-1.4E to 1950f-1.7E	4
$^{1}/_{6}$	2100f-1.8E and higher	6

The amount of bluestain covering the specimen surface was also visually estimated and noted for each piece. The intensity and uniformity of the stain were not noted (i.e.m no distinction was made between whether the stain was light blue or blue-grey).

Table 3: Code to Quantify Bluestain on the Specimen Surface

Stain Code	Amount of Specimen Surface Area Stained
0	Up to $^{1}/_{4}$
1	$^{1}/_{4}$ to $^{1}/_{2}$
2	$^{1}/_{2}$ to $^{3}/_{4}$
3	More than $^{3}/_{4}$

Before testing, all specimens were conditioned to approximately 15% ±2% moisture content as estimated by a handheld resistance-type moisture meter.

[1] Market and end use requirements dictate that the amount of wane permitted in MSR lumber be limited to that generally specifed for Structural Light Framing No.1 or higher; however, this is not a requirement of the product standard.

2.2 Mechanical Test Procedures

2.2.1 Transverse Vibration Modulus of Elasticity

Transverse vibration tests for the modulus of elasticity, E, were carried out using equipment and procedures that meet the requirements of ASTM D6874-03 (ASTM, 2004f). The equipment consists of two load cells, one supporting each end of the specimen, and computer-based data acquisition equipment to note the specimen weight and to record the change in weight over time when the specimen undergoes vibration in the fundamental mode. An algorithm based the Fast Fourier Transform technique was used to determine the fundamental frequency from the weight-time data. The specifics of the transverse vibration E test are summarized in Table 4.

Table 4: Transverse vibration test configuration

Parameter	Setting	Comments
Span	94 ±0.06 inches (2 388 ±1.6 mm)	The span is the specimen length (8-ft. or 2.44 m) minus 1-inch (25.4 mm) of overhang at each end.
Method of excitation		Specimens were pressed downward at mid-span by hand and then quickly released.

2.2.2 Edgewise Bending Tests

Edgewise bending tests for E and modulus of rupture (MOR), were in accordance with ASTM D4761-02a (ASTM 2004d). The specifics of the tests are summarized in Table 5. The bending test procedure used differs slightly from that specified in the NLGA SPS 2. With the exception of the MSRC location in the E and MOR tests, data adjustments were made so that the results are comparable to that specified in the NLGA SPS 2 (Table 6). A data adjustment for effect of the MSRC location on the MOR results was not made because the specimen lengths are relatively short and, in most cases, it would not be physically possible to consistently position the MSRC between the load points. Given that adjustments for the effect of MSRC placement have not yet been standardized, especially when not all the specimens are positioned in the same way, it was decided to randomly position MSRC instead.

All specimens were tested twice in edgewise bending: first to a stress level of about 1590 psi (11.0 MPa), unloaded, and then reloaded to a stress level of about 6000 psi (41.4 MPa). If the specimen failed the proof-load test, the stress level at failure was recorded. The stress level of 6000 psi is about 20% above the minimum bending proof-test level specified for the 2400f-2.0E grade and was selected so that data could be gathered to confirm whether or not the 5^{th} percentile MOR of the 2400f-2.0E grade is being met.

The edgewise-bending E for each specimen was computed from a linear regression analysis of the load-deflection data collected from the second loading. Only those data points collected when the applied load was between about 150 and 450 lbs (0.67 to 2.0 kN) were used in the regression analysis.

Table 5: Edgewise bending test configuration

Parameter	Setting	Comments
Span	59.5 ±0.06 inches (1 511 ±1.6 mm)	Span corresponds to 17 times the standard dry width.
Loading configuration	Third point loading	This corresponds to a half shear span of 19.8 ±0.06 inches (504 ±1.6 mm).
Tension edge selection	Random selection from piece to piece	
Lengthwise positioning	The MSRC is randomly positioned in test span whenever possible.	The specimen lengths (96 in.) are relatively short compared to the test span (59.9 in.). In most cases, it would not be physically possible to longitudinally shift the specimen so that the MSRC is between the load points, which is the NLGA SPS 2 approach.
Loading rate	Constant rate of cross-head movement, 2.5 inch/min (6.4 cm/min)	
Time to maximum stress or failure		Ranging from 12 to 51 seconds, with an average of 20.6 seconds.
Deflection for modulus of elasticity, E, calculations		The deflection used to calculate E is based on the movement of the bending machine crosshead.

Table 6: Differences between NLGA SPS 2 requirements and current study procedures

Parameter	NLGA SPS 2	Current Study	Data Adjustment
Span	73.5 in. (1 867 mm) (21:1 span-to-depth)	59.5 in. (1 511 mm) (17:1 span-to-depth)	Adjust to 21:1 using ASTM D2915 (ASTM, 2004c)
MSRC location in E test	Center piece (MSRC may be outside test span)	MSRC randomly located in span	None
MSRC location in MOR test	MSRC between load points when possible	MSRC randomly located in span	None

2.3 Data Adjustments

2.3.1 Moisture Meter Reading for Species Effects

The moisture content was determined using a 2-pin resistance type moisture meter. Because the entire sample was lodgepole pine that was conditioned to remove all moisture gradients, the moisture meter results were corrected for species effect using the following equation [suggested by Garrahan (1989)] and developed by Salamon (1971) for lodgepole pine samples collected for the Canadian in-grade lumber testing program:

$$MC = 1.004 \cdot MMR_{D.fir} + 1.483 \qquad [1]$$

where

MC = estimated moisture content (%)
$MMR_{D.fir}$ = moisture meter reading (%) at the default species setting (Douglas-fir)

2.3.2 Edgewise-Bending E for Machine Deflection and Test Configuration

Edgewise-bending E tests were carried out on a bending test machine developed by Forintek that determines the specimen deflection from the movement of the loading crosshead, as permitted by ASTM D4671 (ASTM 2004d). It is recognized that this method of displacement measurement may include extraneous components such as machine frame deflection and specimen crushing at the load points. Results from the Forintek bending machine are normally adjusted using the following equation to produce results comparable to that obtained from an ASTM D198 test (ASTM 2004a):

$$\frac{1}{E_{adj}} = \frac{1}{E_{test}} - 0.00591 \cdot H \qquad [2]$$

where

E_{adj} = E value after adjustment, 10^6 psi
E_{test} = E value before adjustment, 10^6 psi
H = nominal specimen width, in

Because the data are adjusted to the D198 basis, the adjustment accounts for machine deflection, crushing at the load-points and the influence of shear deformations on the beam deformation under third-point loading. This latter adjustment is described in Clause 4.3 in ASTM D2915 (ASTM 2004c).

2.3.3 Edgewise-bending and Transverse Vibration E and MOR for Moisture Content

The edgewise-bending E results were all adjusted to a value corresponding to a 15% moisture content using the equation found in ASTM D1990 (ASTM, 2004b). Although the adjustment has traditionally only been used for the edgewise-bending results, it was assumed to be also applicable to the transverse vibration E.[2]

2.3.4 Edgewise-bending E and MOR for Overall Span

The edgewise-bending E and MOR test results were adjusted from a span corresponding to a span-to-depth ratio of 17:1 to a span corresponding to a ratio of 21:1 in accordance with ASTM D2915 (ASTM 2004c).

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[2] The transverse vibration E is computed from the mass of the piece and the fundamental frequency of the piece in transverse vibration. Because of the effect of moisture content on the mass of the specimen, the cross-section size, and the modulus of elasticity, it is unclear whether the equation originally developed for static tests is applicable. But because all specimens were conditioned to a moisture content range of 13% to 17%, the adjustments represent only a few percentage adjustments to the E and the mass, so it was assumed that the D1990 adjustment could be reasonably applied to the transverse vibration E results.

As noted in Table 6, no adjustments were made to account for the placement of the MSRC. Although the NLGA SPS 2 requires that the MSRC be located between the middle two load points whenever possible, published bending design values are based on a random location of the MSRC within the test span (i.e., between the outer support points, but not necessarily always between the inner two load points).

2.4 Estimates of MSR Lumber Recovery

2.4.1 Grade Combinations

In order to estimate the recovery, the MSR lumber grading process was simulated on a computer using the lumber test data collected in this study. Under the North American system, generally called the "output control" method, each operation is required to establish machine settings such that the lumber from the grading process, when evaluated according to the standard procedures (such as that outlined in NLGA SPS 2), is meeting the grade specifications. The simulation would be similar to how lumber would be graded at an MSR lumber producing facility.[3]

Three grade combinations were analyzed (Table 7). The grade labelled "Reject" consists of the pieces remaining after all the MSR grades are extracted. Typically, a visual grade (such as the Standard Light Framing) may be produced from the Reject. But because the study only involves pieces that are visually No. 2 or higher, pieces in Reject grade would also meet the visual requirements of the No. 2 Structural Light Framing grade.

Table 7: Grade combinations analyzed

Scenario	Grade Combinations			
1	2400f-2.0E	2100f-1.8E	1650f-1.5E	Reject
2	-	2100f-1.8E	1650f-1.5E	Reject
3	-	-	1650f-1.5E	Reject

Note: "Reject" consist of all pieces that do not meet the MOE and visual requirements of the lowest MSR lumber grade being considered.

2.4.2 Grade Boundary Optimization

There are a number of different approaches for selecting grade boundary settings. At a minimum, they should be selected so that production from each of the MSR grades can shown to meet the requirements of the product standard (e.g., NLGA SPS 2). In practice, machine grade boundaries are selected both to maximize the value of the lumber produced (which considers not only the value of the grade, but also the market demand for the grades in production), and ensure that the process does not go "out-of-control" by chance too often.[4]

For the purposes of this study, the grade boundaries were selected such that the volume of each grade, starting from the highest grade, is maximized. The sequence of grade boundary selection

[3] In an actual facility, it is likely that the mill will be processing a species mix rather than a single species such as lodgepole pine. Therefore the machine settings and recovery estimates here may not be directly compared.
[4] A process is considered to be "out-of-control" when the test results from a random sample of lumber from a process suggests that the product is not in conformance to the applicable product standard.

is important because the setting affects the process characteristics (e.g., average and 5th percentile properties) of both grades on either side of the grade boundary.

A flowchart describing the steps used to determine the grade boundary settings for each grade combination is given in Section 3.3.2.

3 Results

3.1 Summary Statistics on Mechanical Properties by Treatment Groups

Although an equal number of pieces were provided from each MC sort group, some pieces were culled from the test sample because they did not meet the visual grade requirements of the Structural Light Framing No.2 grade. The number of specimens in each combination of drying treatment and dry sort ranged from 168 to 180 (Table 8). There was no single dominant reason for rejecting a piece; the most common was because of excessive wane.

Table 8: Summary statistics by moisture and drying treatment group

Moisture Sort	Count	Trans. Vibration E (10^6 psi)		Edgewise Bending E (10^6 psi)		Modulus of Rupture (psi)			
						NP 5th %ile			NP
		Means	Std.Dev.	Means	Std.Dev.	Est.	95% LCI	95% UCI	25th %ile
Dry	516	1.57	0.28	1.43	0.26	3490	3212	3776	4891
Treatment 1	180	1.57	0.27	1.42	0.24	3728	2912	4033	4967
Treatment 2	168	1.59	0.30	1.46	0.27	3560	3166	4098	5147
Treatment 3	168	1.53	0.29	1.41	0.28	3250	2531	3522	4694
Mid	528	1.76	0.28	1.58	0.26	4333	3813	4513	5234
Treatment 1	180	1.75	0.27	1.55	0.26	4003	3076	4359	5155
Treatment 2	168	1.78	0.29	1.62	0.26	4873	3813	5200	5345
Treatment 3	180	1.75	0.27	1.56	0.26	4054	3009	4512	5248
Wet	492	1.83	0.30	1.63	0.28	4426	4048	4543	5196
Treatment 1	164	1.89	0.32	1.67	0.28	4699	3667	4930	5143
Treatment 2	162	1.82	0.29	1.63	0.30	4413	3889	4669	5243
Treatment 3	166	1.79	0.27	1.60	0.25	4425	3880	4527	5245
All Groups	1536	1.72	0.31	1.55	0.28	3974	3791	4122	5177

NOTE: NP 5th %ile = non-parametric lower 5th percentile estimate; 95% LCI = 95% lower confidence interval; 95% UCI = 95% upper confidence interval; NP 25th %ile = non-parametric lower 25th percentile estimate.

Based on the non-parametric 95% confidence intervals computed for the lower 5th percentile MOR values, the differences in the MOR values between drying treatments for all MC sorts did not appear to be statistically significant. Between MC sorts, the only statistically significant difference in the 5th percentile MOR was between the wet and dry sort samples.

In general, the Analysis of Variance (ANOVA) (see Appendix I) shows no significant difference ($p < 0.05$) in the mean edgewise bending and transverse vibration MOE between the three drying treatments for each MC sort. The differences in the mean MOE between the MC sorts were, however, found to be significant.

3.2 Observations of Bluestain within the Sample

3.2.1 Distribution of Bluestain between Treatment Groups

The distribution of bluestain across the treatment groups and moisture sorts is summarized in Figure 1.

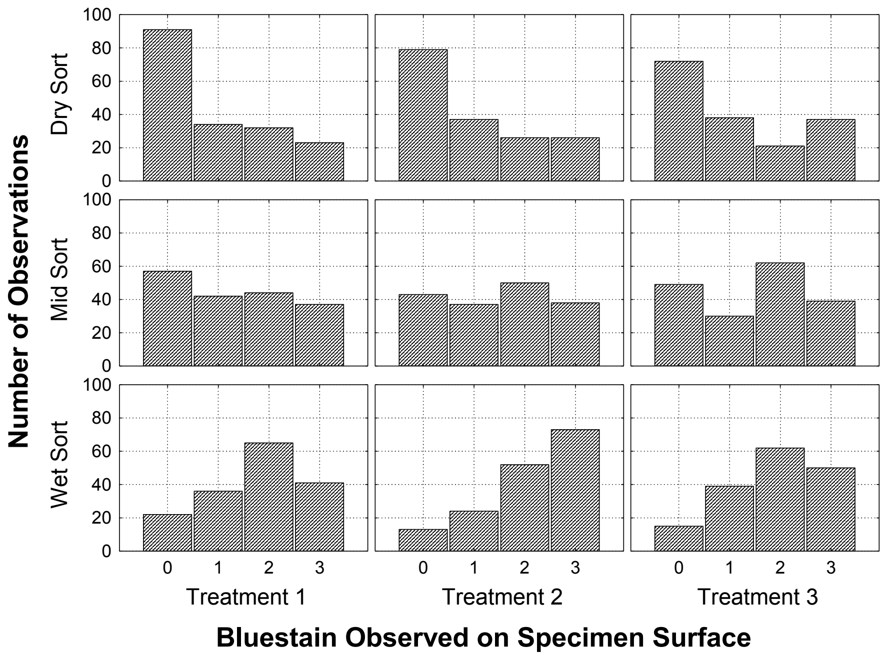

Figure 1: Distribution of pieces with specified degree of bluestain (see Table 3) by drying treatment and MC sort

Given that the amount of bluestain is not affected by the drying treatment, Figure 1 suggests the following:

- Bluestain was not as prevalent in samples found in the low moisture content or "dry" sort. It is likely that these pieces are predominantly heartwood pieces, which naturally would not be stained.
- The high moisture content or "wet" sort pieces tend to be skewed towards pieces that possess bluestain but not necessarily 100% bluestain. This is expected as sapwood pieces will have relatively higher moisture content than heartwood pieces, and it is the sapwood that will show bluestain. The observation that pieces with greater than 75% bluestain is less likely than pieces with 50% to 75% bluestain is likely due to two factors: that not all sapwood will be stained, and even if the sapwood were entirely stained, it is unlikely that a piece will be 100% sapwood. The latter factor will depend on the size of the log and the log breakdown strategy.
- In the mid-sort, there appears to be a uniform amount of bluestain on the pieces across the four categories.

The relatively similar distribution of bluestain across MC sorts within a drying treatment shows that the samples are reasonably matched across drying treatments, and possibly with respect to the amounts of heartwood and sapwood.

3.2.2 Effect of Degree of Bluestain on the Mechanical Properties

Figure 2 to Figure 4 show, respectively, the edgewise-bending E, transverse vibration E, and MOR by MC sort, MC treatment and degree of bluestain. There are no obvious trends in the average results for the three mechanical properties with respect to the amount of bluestain covering the pieces. This is consistent with the findings in Lum (2003). If any, the data suggest a tendency for lower average E and MOR in the low MC or "dry" sort samples, and in the pieces with no bluestain. This observation was not evident in the Lum (2003) study as that study focused on comparing bluestained and unstained sapwood. In the current study, the results are confounded by the differences in the mechanical properties of heartwood and sapwood. As discussed in Section 3.2, non-stained wood could be either heartwood or sapwood without bluestain. Each would produce a different correlation between the presence of bluestain and the mechanical properties.

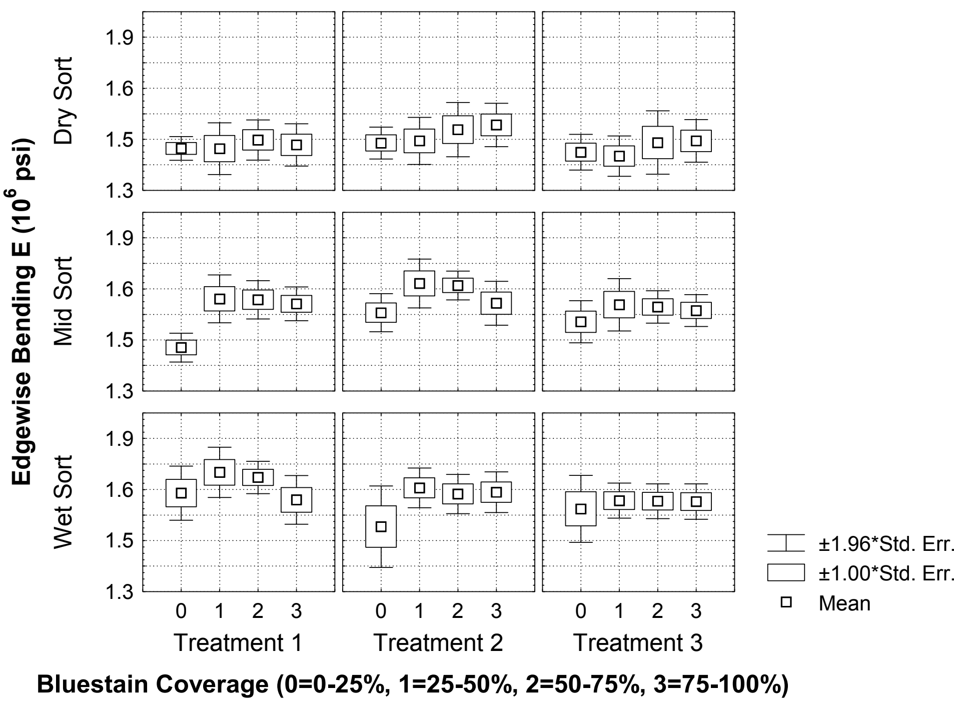

Figure 2: Edgewise bending E by treatment, MC sort and degreee of bluestain

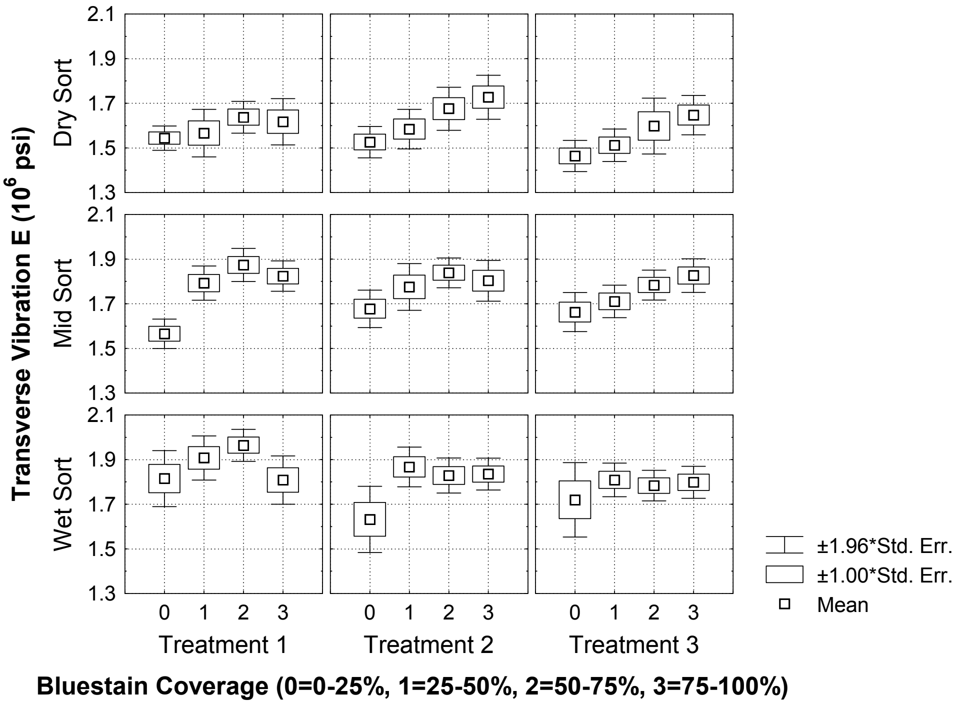

Figure 3: Transverse vibration E by treatment, MC sort and bluestain coverage

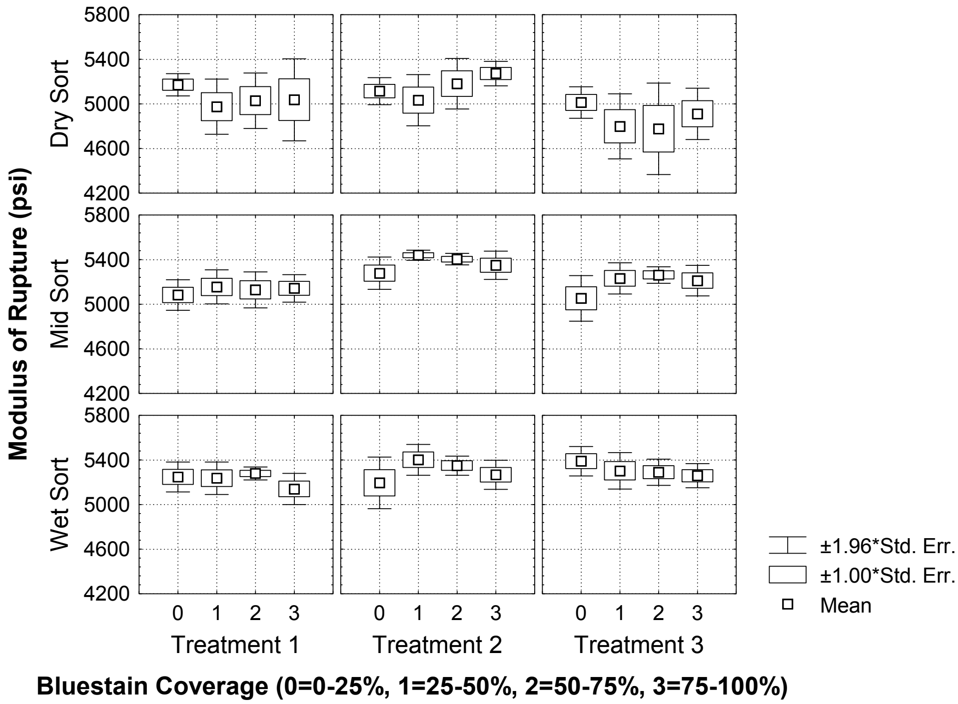

Figure 4: Modulus of rupture (MOR) by treatment, MC sort and bluestain coverage

3.3 MSR Lumber Grade Recovery

3.3.1 Edgewise Bending versus Transverse Vibration E

Although there is a strong correlation between the edgewise-bending and transverse vibration E, the relationship is not perfect. The same could be expected of the relationship between the edgewise-bending E and the E measured on a production line to sort lumber on a continuous basis. For the purpose of the machine grading simulation in this study, the transverse vibration E was used as the E for sorting purposes, while the edgewise-bending E (as specified in NLGA SPS 2) was used for computing the process E.

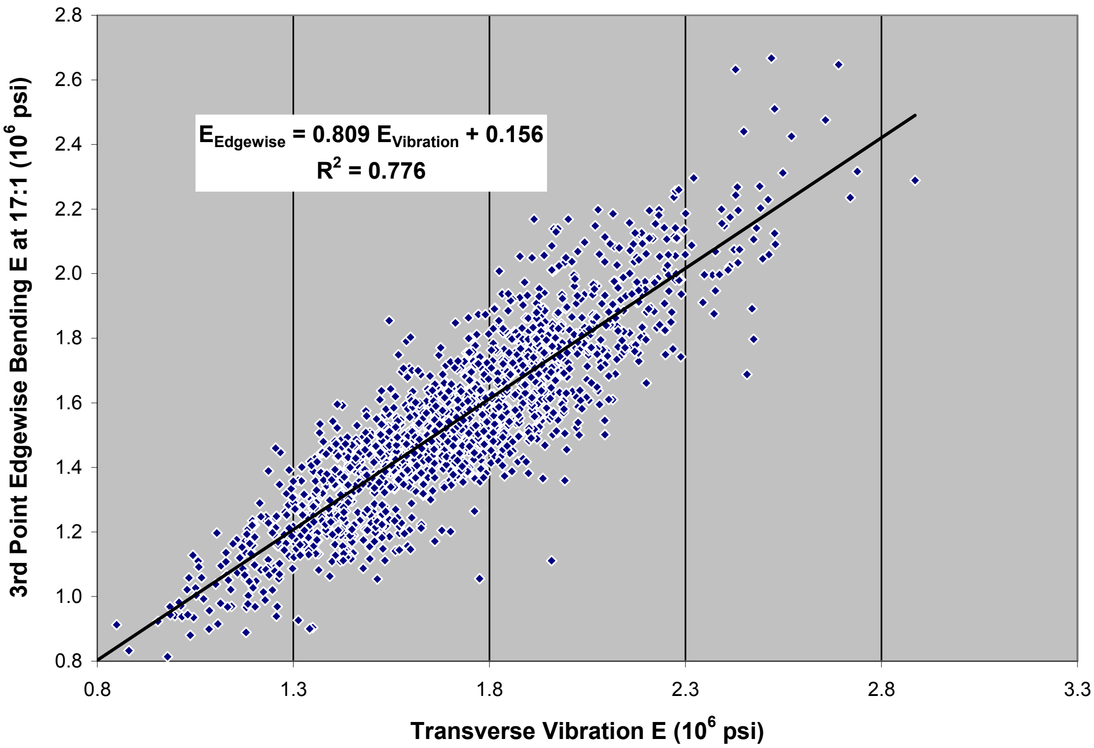

Figure 5: Relationship between the edgewise and flatwise bending E

In general, the transverse vibration E result estimates a higher E value than the edgewise-bending E result. However, this relationship is expected to vary depending on the equipment used.

3.3.2 Grade Recovery Results

The grade recovery estimates were obtained following the procedures shown in Figure 6. Using the results from the visual grading, the edgewise-bending tests and the transverse vibration E tests, the MSR lumber grade recovery for the three grade scenarios listed in Table 7 were estimated by treatment and then by MC sort. As indicated in Table 8, each drying treatment or MC sort contains data from about 500 pieces of lumber. The MSR recovery analysis was also undertaken by combining data from all drying treatments and MC sorts. There was insufficient data for each combination of drying treatment and MC sort to determine the MSR lumber recovery as each cell contained data from only about 170 pieces.

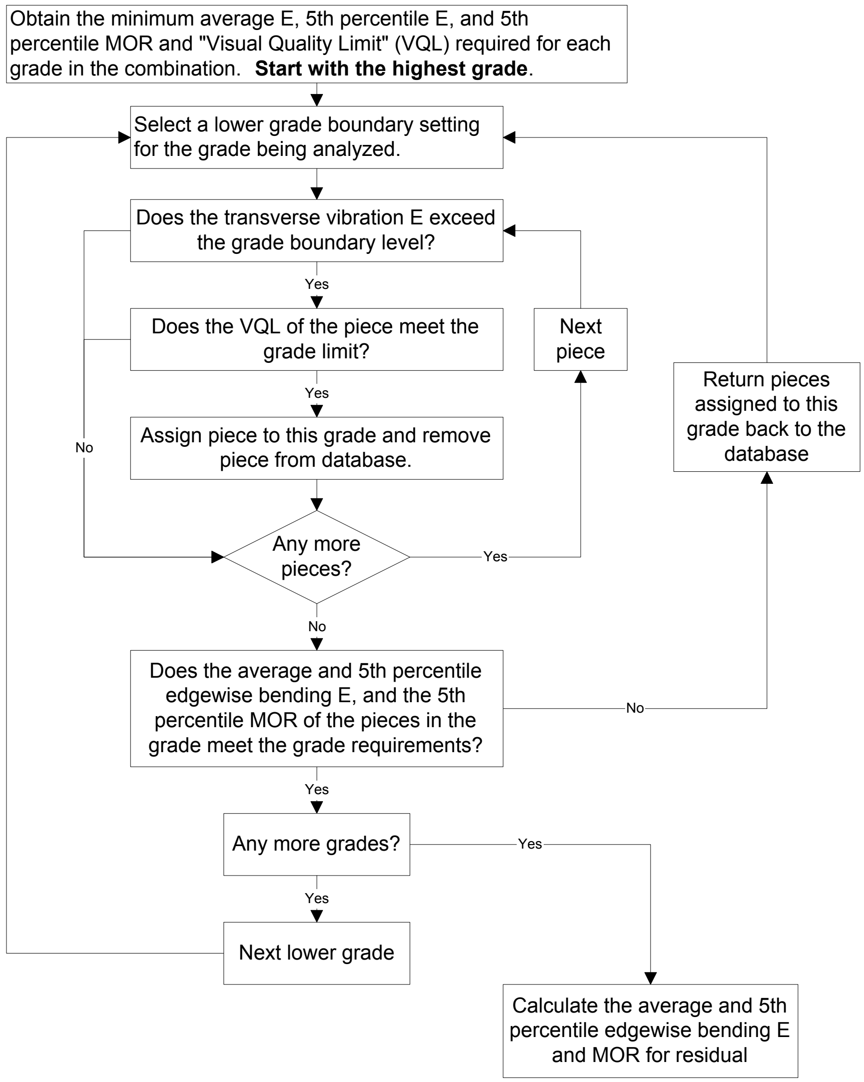

Figure 6: Steps in select MSR lumber grade boundaries

Summary statistics from the MSR recovery analysis are included in Appendix II and Appendix III. Results from the analysis of the overall sample (all drying treatments and MC sorts) are shown graphically for the three grade combinations listed in Table 7, in Figure 7 to Figure 9 by MC sort, and in Figure 10 to Figure 12 by drying treatment. Although this mill is currently producing machine graded lumber, it should be noted that the results from this study might not exactly match the "overall" recovery actually observed at this mill. Equal samples were collected from each of the three moisture (MC) sorts: dry, mid, and wet. In order to obtain a figure that is comparable to the overall recovery, the MSR recovery results will need to be weighted by a factor representing the actual proportion of pieces falling into each of the MC sorts.

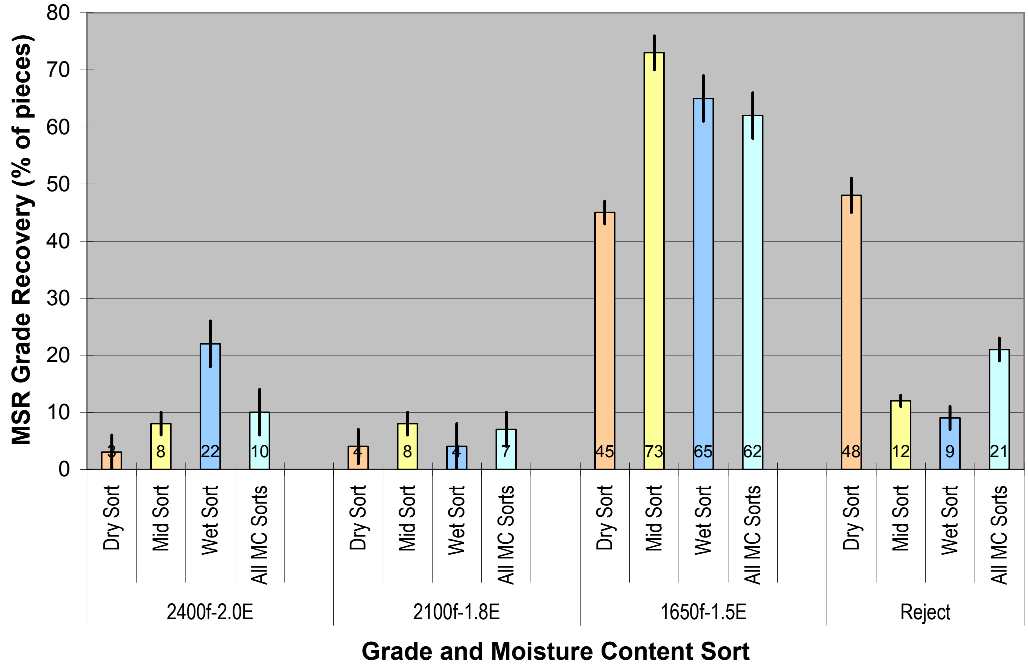

Figure 7: **Estimated recovery and 95% confidence intervals by MC sort from 3-grade combination (see Appendix II)**

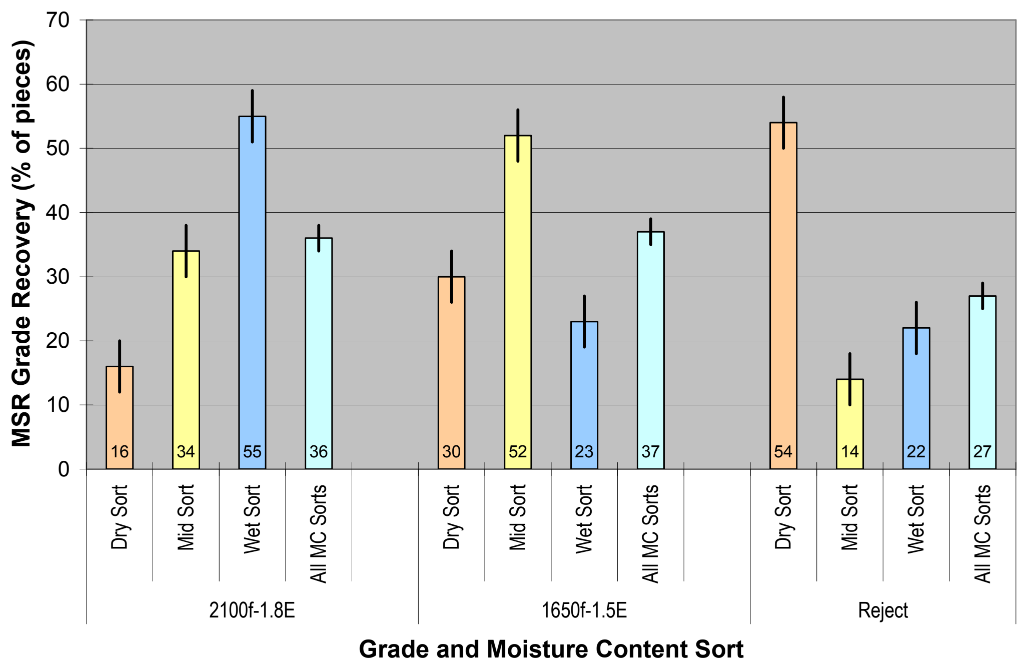

Figure 8: **Estimated recovery and 95% confidence intervals by MC sort from 2-grade combination (see Appendix II)**

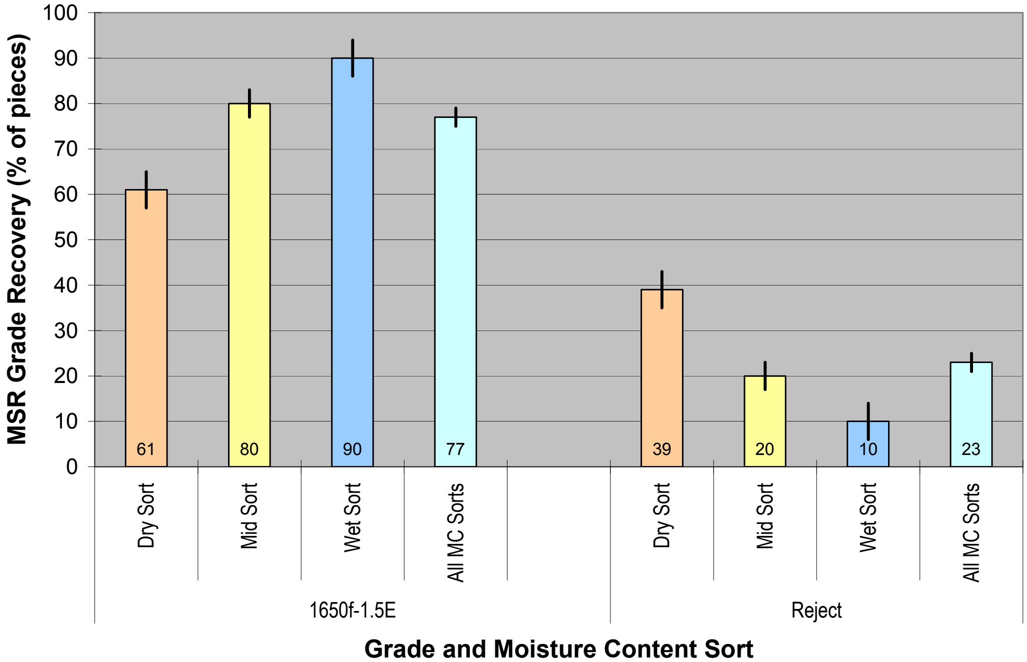

Figure 9: **Estimated recovery and 95% confidence intervals by MC sort from 1-grade combination (see Appendix II)**

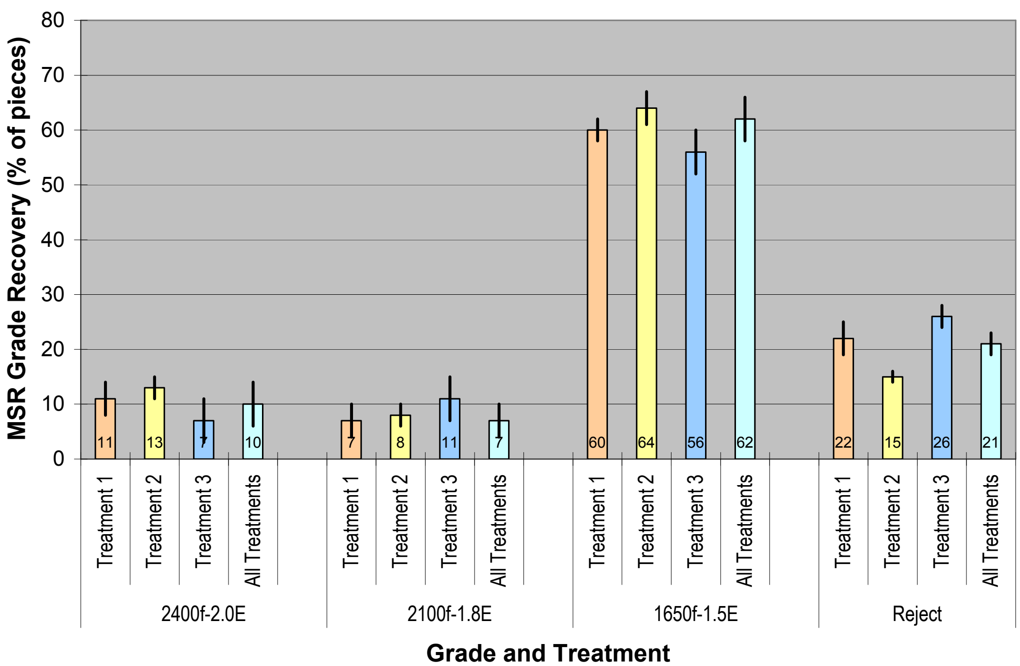

Figure 10: **Estimated recovery and 95% confidence intervals by drying treatment from 3-grade combination (see Appendix III)**

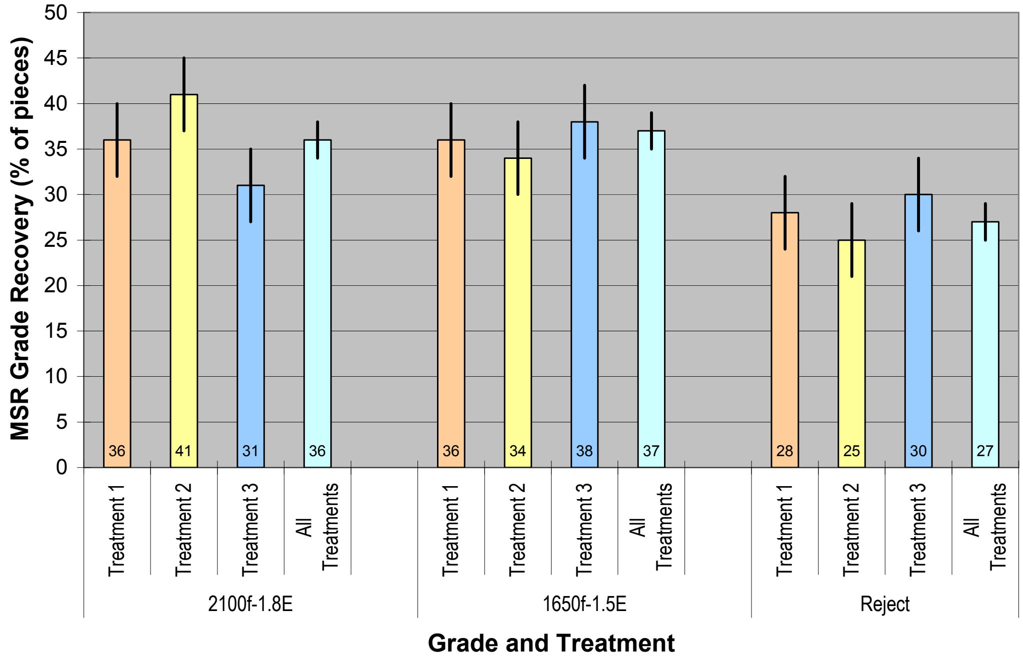

Figure 11: **Estimated recovery and 95% confidence interval by drying treatment from 2-grade combination (see Appendix III)**

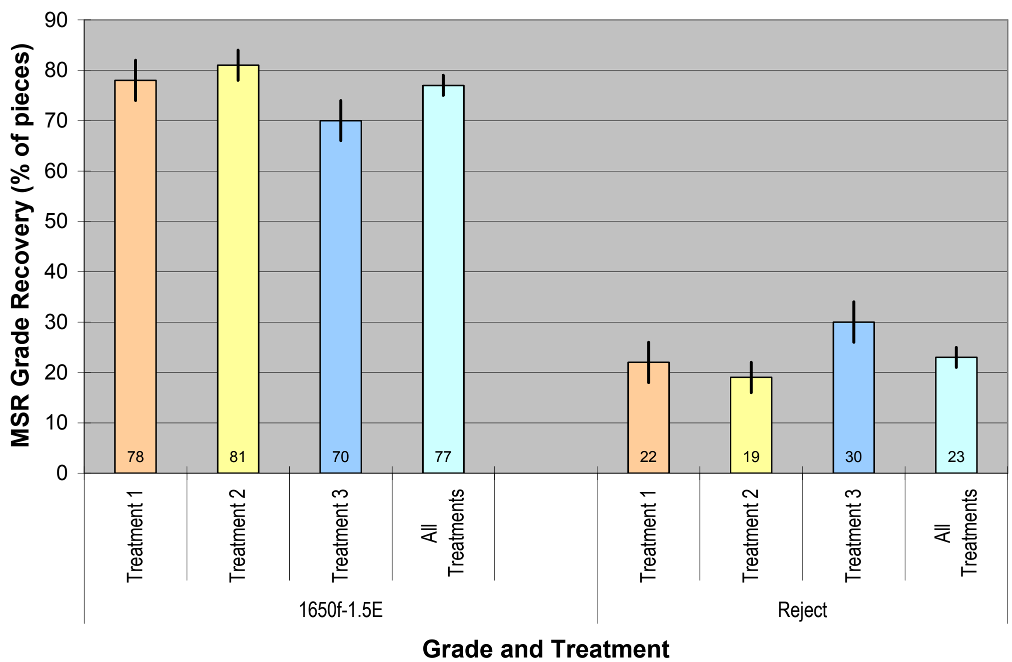

Figure 12: **Estimated recovery and 95% interval by drying treatment from 1-grade combination (see Appendix III)**

3.4 Discussion

3.4.1 Overall MSR Lumber Recovery

The overall MSR lumber recovery observed from this sample is typical of that expected from SPF and lodgepole pine lumber. As is with the case of nominal 2-in. by 4-in. (38 by 89 mm) SPF lumber, the grade boundary selection is controlled by the modulus of elasticity requirements rather than the bending strength requirements. That is, once a grade boundary setting has been selected to meet the modulus of elasticity requirements, no further adjustments to the boundary settings are required to meet the MOR requirements.

3.4.2 Effect of Drying Treatment

There is some, but not consistent, evidence that Treatment 3 (Figure 10 to Figure 12) tends to impact the recovery of higher MSR lumber grades (2400f-2.0E and 2100f-1.8E) and result in higher volumes of rejects (i.e., production of non-MSR grades). It is not clear what is the cause of this or whether it is due to sampling error.

3.4.3 Effect of Bluestain

While there appears to be an effect of bluestain on the MSR lumber recovery, it is not detrimental. This is likely attributed to the fact that lodgepole pine sapwood will tend to have higher MOE values than heartwood. This is supported by the observation that a significantly higher volume of bluestained lumber appears in the wet sort as opposed to the dry sort.

4 Conclusions

Bending strength and modulus of elasticity results from a sample of nominal 2-in. by 4-in. (38 by 89 mm) lumber from post-MPB wood has been developed for the purpose of assessing the MSR lumber grade recovery. The analysis did not show any statistically significant difference in bending modulus of elasticity from the three drying treatments studied by Oliveira *et al*. (2005). The MSR lumber grade recovery of three typical grade combinations is presented and the results are typical of 2x4 SPF lumber where a high proportion of the lumber is lodgepole pine. The results also support previous findings that bluestain does not impact the mechanical properties of lodgepole pine.

5 Acknowledgements

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Appendix I Analysis of Variance (Drying Treatment x MC Sort)

Duncan test for Mean Edgewise-Bending MOE
Probabilities for Post Hoc Tests

		Mean MOE =	1.422	1.456	1.411	1.546	1.622	1.562	1.672	1.629	1.602
MC Sort			{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}
Dry	1	{1}		0.230	0.701	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Dry	2	{2}	0.230		0.135	**0.002**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Dry	3	{3}	0.701	0.135		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Mid	1	{4}	**0.000**	**0.002**	**0.000**		**0.014**	0.575	**0.000**	**0.008**	0.067
Mid	2	{5}	**0.000**	**0.000**	**0.000**	**0.014**		**0.048**	0.107	0.810	0.478
Mid	3	{6}	**0.000**	**0.000**	**0.000**	0.575	**0.048**		**0.000**	**0.032**	0.171
Wet	1	{7}	**0.000**	**0.000**	**0.000**	**0.000**	0.107	**0.000**		0.143	**0.025**
Wet	2	{8}	**0.000**	**0.000**	**0.000**	**0.008**	0.810	**0.032**	0.143		0.375
Wet	3	{9}	**0.000**	**0.000**	**0.000**	0.067	0.478	0.171	**0.025**	0.375	

Duncan test for Transverse Vibration MOE
Probabilities for Post Hoc Tests

		Mean MOE =	1.574	1.593	1.532	1.747	1.775	1.748	1.893	1.821	1.788
MC Sort			{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}
Dry	1	{1}		0.537	0.170	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Dry	2	{2}	0.537		0.059	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Dry	3	{3}	0.170	0.059		**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Mid	1	{4}	**0.000**	**0.000**	**0.000**		0.387	0.975	**0.000**	**0.029**	0.226
Mid	2	{5}	**0.000**	**0.000**	**0.000**	0.387		0.371	**0.000**	0.159	0.678
Mid	3	{6}	**0.000**	**0.000**	**0.000**	0.975	0.371		**0.000**	**0.027**	0.219
Wet	1	{7}	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**		**0.021**	**0.001**
Wet	2	{8}	**0.000**	**0.000**	**0.000**	**0.029**	0.159	**0.027**	**0.021**		0.281
Wet	3	{9}	**0.000**	**0.000**	**0.000**	0.226	0.678	0.219	**0.001**	0.281	

Appendix II Grade Recovery Results by MC Sort

3-Grade Combination Recovery

Grade	MC Sort	Grade Recovery		
		Estimate	Upper 95% CI	Lower 95% CI
2400f-2.0E	Dry Sort	3	6	0
	Mid Sort	8	10	6
	Wet Sort	22	26	18
	All MC Sorts	10	14	6
2100f-1.8E	Dry Sort	4	7	1
	Mid Sort	8	10	6
	Wet Sort	4	8	0
	All MC Sorts	7	10	4
1650f-1.5E	Dry Sort	45	47	43
	Mid Sort	73	76	70
	Wet Sort	65	69	61
	All MC Sorts	62	66	58
Reject	Dry Sort	48	51	45
	Mid Sort	12	13	11
	Wet Sort	9	11	7
	All MC Sorts	21	23	19

2-Grade Combination Recovery

Grade	MC Sort	Grade Recovery		
		Estimate	Upper 95% CI	Lower 95% CI
2100f-1.8E	Dry Sort	16	20	12
	Mid Sort	34	38	30
	Wet Sort	55	59	51
	All MC Sorts	36	38	34
1650f-1.5E	Dry Sort	30	34	26
	Mid Sort	52	56	48
	Wet Sort	23	27	19
	All MC Sorts	37	39	35
Reject	Dry Sort	54	58	50
	Mid Sort	14	18	10
	Wet Sort	22	26	18
	All MC Sorts	27	29	25

1-Grade Combination Recovery

Grade	MC Sort	Grade Recovery		
		Estimate	Upper 95% CI	Lower 95% CI
1650f-1.5E	Dry Sort	61	65	57
	Mid Sort	80	83	77
	Wet Sort	90	94	86
	All MC Sorts	77	79	75
Reject	Dry Sort	39	43	35
	Mid Sort	20	23	17
	Wet Sort	10	14	6
	All MC Sorts	23	25	21

Appendix III Grade Recovery Results by Drying Treatment

3-Grade Combination Recovery

Grade	Drying Treatment	Grade Recovery Estimate	Upper 95% CI	Lower 95% CI
2400f-2.0E	Treatment 1	11	14	8
	Treatment 2	13	15	11
	Treatment 3	7	11	3
	All Treatments	10	14	6
2100f-1.8E	Treatment 1	7	10	4
	Treatment 2	8	10	6
	Treatment 3	11	15	7
	All Treatments	7	10	4
1650f-1.5E	Treatment 1	60	62	58
	Treatment 2	64	67	61
	Treatment 3	56	60	52
	All Treatments	62	66	58
Reject	Treatment 1	22	25	19
	Treatment 2	15	16	14
	Treatment 3	26	28	24
	All Treatments	21	23	19

2-Grade Combination Recovery

Grade	Drying Treatment	Grade Recovery Estimate	Upper 95% CI	Lower 95% CI
2100f-1.8E	Treatment 1	36	40	32
	Treatment 2	41	45	37
	Treatment 3	31	35	27
	All Treatments	36	38	34
1650f-1.5E	Treatment 1	36	40	32
	Treatment 2	34	38	30
	Treatment 3	38	42	34
	All Treatments	37	39	35
Reject	Treatment 1	28	32	24
	Treatment 2	25	29	21
	Treatment 3	30	34	26
	All Treatments	27	29	25

1-Grade Combination Recovery

Grade	Drying Treatment	Grade Recovery Estimate	Upper 95% CI	Lower 95% CI
1650f-1.5E	Treatment 1	78	82	74
	Treatment 2	81	84	78
	Treatment 3	70	74	66
	All Treatments	77	79	75
Reject	Treatment 1	22	26	18
	Treatment 2	19	22	16
	Treatment 3	30	34	26
	All Treatments	23	25	21

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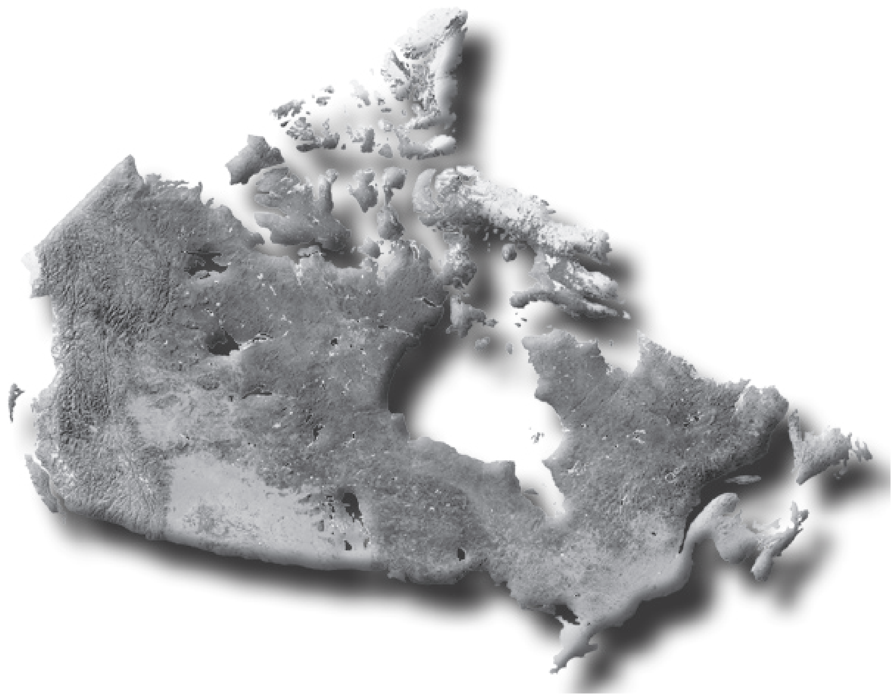

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