ETABLISHING DESIGN VALUES AND DURABILITY ASSESSMENT OF WESTERN JUNIPER

Research Project Report

PROJECT 304-721

Oregon Department of Transportation

ESTABLISHING DESIGN VALUES AND DURABILITY ASSESSMENT OF WESTERN JUNIPER

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16. Abstract

Western juniper is a conifer that is native to Oregon, California, Washington, Nevada, and Idaho. Juniper is known to have highly decay resistant heartwood and is a popular choice for finished furniture. With recent forest management practices over the past 100 years have resulted in an immense population increase in western juniper stands, transforming the grasslands/sagebrush into juniper forests. Landowners have been encouraged to cutback western juniper to restore grassland habitat, but there is no major market associated with juniper. This study assessed the strength and durability properties of western juniper in order to develop design values in collaboration with the West Coast Lumber Inspection Bureau.
Samples were harvested from three locations in eastern Oregon, one location in northeast California, and one location in southwest Idaho. Tests were performed according to procedures described in ASTM Standard D143 small-clear specimens for compression, bending, and shear. Average strength values were calculated and compared to similar wood species. Most properties were similar to those of other species, but modulus of elasticity was significantly lower. The differences between species might be attributed to cell wall structure and distribution of lignin in the cells. Design values for western juniper were calculated using the strength values following the ASTM Standard D245 procedure for establishing structural grades and related allowable properties for visually graded lumber.
Durability of western juniper was assessed using laboratory decay tests, marine tests, and ground contact exposure. The long term marine durability and ground contact tests are still on going. The laboratory decay test indicated that western juniper heartwood was highly resistant to attack by brown and white rot fungi.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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EXECUTIVE SUMMARY

Western juniper (*Juniperus occidentalis*) is a conifer that is native to Oregon, California, Washington, Nevada, and Idaho. Juniper is known to have highly decay resistant heartwood and is a popular choice for finished furniture. With recent forest management practices over the past 100 years have resulted in an immense population increase in western juniper stands, transforming the grasslands/sagebrush into juniper forests. Landowners have been encouraged to cutback western juniper to restore grassland habitat, but there is no major market associated with juniper. This study assessed the strength and durability properties of western juniper in order to develop design values in collaboration with the West Coast Lumber Inspection Bureau (WCLIB). The data will be presented to American Lumber Standard Committee (ALSC) for inclusion in the National Design Specification. Design values assigned to western juniper will allow contractors to use this species in structural and non-structural applications, especially for State funded projects.

Samples were harvested from three locations in eastern Oregon, one location in northeast California, and one location in southwest Idaho. Tests were performed according to procedures described in ASTM Standard D143 small-clear specimens for compression, bending, and shear. Average strength values were calculated and compared to similar wood species. Most properties were similar to those of other species, but modulus of elasticity was significantly lower. The differences between species might be attributed to cell wall structure and distribution of lignin in the cells. Design values for western juniper were calculated using the strength values following the ASTM Standard D245 procedure for establishing structural grades and related allowable properties for visually graded lumber.

Durability of western juniper was assessed using laboratory decay tests, marine tests, and ground contact exposure. The long term marine durability and ground contact tests are still on going. The laboratory decay test indicated that western juniper heartwood was highly resistant to attack by brown and white rot fungi.

1.0 INTRODUCTION AND OBJECTIVE

Western juniper is a coniferous tree species that grows to 6 to 18 m tall and a diameter of approximately 0.3 to 0.9 m. It thrives in a continental climate, with hot dry summers, cold winters, and precipitation between 230 to 355 mm/year. Western juniper is native to California, Oregon, Idaho, and parts of Nevada and Washington. Juniper cover has drastically increased in the past century as a result of the introduction of livestock grazing, increased amounts of CO_2, and the main cause, fire suppression (Miller et al. 2005). Western juniper has drastically altered the natural habitat by shading out sagebrush and consuming excessive amounts of water. Western juniper can consume up to 151 liters of ground water per day if adequate soil moisture is available (Bedell et al. 1993). Western juniper encroachment in these areas has changed the landscape by decreasing grass, forbs and shrub vegetation. Vegetation decline has caused a corresponding reduction in wildlife species in juniper forested areas (Bedell et al. 1993). Landowners have been encouraged to cut back juniper stands on their land to halt the spread of western juniper and restore the native grasses. The primary way land owners control western juniper is to bulldoze stems over or pull them down using chain. These methods produced considerable soil disturbance and result in high nutrient loss. The recommended method for western juniper removal is to chainsaw the trees and then haul them out to be processed for alternative uses. This procedure can be costly, creating little incentive for landowners. This has created a large volume of available western juniper, with few options for utilization.

There has been some investigation into creating products from western juniper like pencil stock, essential oils, and hardboard, but these markets have not developed to the extent required to encourage restoration (Leavengood 2008). There are a few niche markets where western juniper has been utilized. Wine vineyards have used juniper posts to support grape vines, since juniper is naturally durable and does not need chemical treatment for preservation. Small portable shacks provide another niche market for juniper. These shacks are generally manufactured from western red cedar, another naturally durable wood species. The natural durability of juniper makes it a good fit for this type of application. The lack of a market for western juniper is due in part to the limited knowledge and needs for data to be published on the properties of this species.

Examining markets that utilize treated or naturally durable wood species could open up avenues for western juniper utilization. Western juniper has highly fungal and insect resistant heartwood, due to the presence of extractives including cedrol (Highley 1995). Lignin levels are higher in western juniper heartwood than in most other naturally durable softwoods, such as western red cedar or redwood when placed in ground contact (Morrell et al. 1999). In 2014, the State of Oregon approved western juniper heartwood as an alternative material for areas subjected to moisture. The material must meet the definition of “naturally durable” by the Oregon Structural Specialty Code (OSSC) and the Oregon Residential Specialty Code (ORSC) (State of Oregon Building Codes Division

2014). This allows western juniper to be used for residential construction, most notably as a sill plate in a house. The "naturally durable wood" definition entails being decay and termite resistant, and was derived from prior research (Morrell et al. 1999).

Allowing western juniper as an alternative building material in applications calling for naturally durable wood has opened a larger market for this species. However, engineers and contractors need to know the material properties of the wood they are using including factored values for design or "design values". Design values are created by collecting test data for multiple mechanical properties of a material and then statistically analyzing them to generate the lower 5th percentile value. Engineers can apply design values to a multitude of adjustment factors, such as load duration and wet service, to obtain a value for designing a structure.

Burke (2008) studied compression, tension, bending, shear, and hardness of western juniper, and reported the average values, but did not convert these values to design values. Raw data for the mechanical tests of each wood sample must be compiled in a specific manner. Unfortunately, the Burke data was lost before they could be properly evaluated. Therefore, there are currently no published design values for western juniper.

Design values are especially important because they are required in government-funded projects even as a non-structural material or in landscaping. These values must be listed in the National Design Specification (NDS) for Timber Construction. The absence of design values for juniper is another impediment to utilization, even for non-structural and landscaping material.

The procedures for development of design values for a wood species in the National Design Specification for Timber Construction (NDS) consists of testing samples from many different locations and going through the process of certification as laid out by the American Lumber Standards Committee (ALSC). The first step in creating design values for a species is to establish a testing and material protocol that outlines the type of testing being conducted, number of tests being conducted and the geographical origin of the material to be obtained. Once the material is procured from the listed geographical locations, the samples are prepared for testing according to relevant testing methods. The sample size needs to be sufficiently robust to obtain the lower 5th percentile. After testing is complete, data are analyzed by a professional engineer affiliated with a certification agency listed in the NDS. For this study, the West Coast Lumber Inspection Bureau (WCLIB) analyzed the data and presented its report to ALSC for their approval and subsequent inclusion in the next NDS. After ALSC's review the values and the report will be handed off to American Wood Council who publishes the NDS. Mechanical and durability testing were performed on western juniper samples from different locations within the growing range. The testing was performed in the Department of Wood Science and Engineering at Oregon State University, and certified by the West Coast Lumber Inspection Bureau. Completing the process of adding western juniper to the design codes and standards will allow for the use of juniper in commercial buildings. Increased utilization will stimulate the economy of rural areas where western juniper grows.

The objectives of this study were to:

1. Test multiple mechanical properties of western juniper as well as calculating the green/dry ratio for shear and compression.

2. Analyze western juniper test data to formulate design values for the standards and codes.

3. Assess the durability properties of western juniper against marine borers and fungi.

2.0 MATERIALS AND METHODS

2.1 MATERIALS

Lumber samples were randomly collected from Oregon, California, and Idaho. Five different western juniper processing facilities harvested and milled the juniper to size. The number of samples from each state was based on the relative volume of timber present in that state. Oregon contained the most standing western juniper with approximately 66%, followed by California with 21% and Idaho with 13% (BLM 2015). Hence, the sample size distribution between the states was based on the percentage of western juniper in each state. Since Oregon contained the highest volume of western juniper, material was obtained from three different sites within Oregon, while samples were collected from only one site in each of the other states. The three locations for Oregon were based on the regions where western juniper predominated and represented three different geographical conditions. The first site was in Lake County in South Central Oregon, the second site was near Crook County, in Central Oregon, and the last site was in Harney County in Eastern Oregon. The California samples were obtained from the northeastern region of California in Modoc County. The Idaho samples were obtained from the southeast region in Owyhee County. The materials procured were either in the form of a 101.6 x 101.6 mm (4 x 4 in.) or 152.4 x 152.4 mm (6x6 in.) posts approximately 2.44 m long (8 ft.).

The posts were cut into samples for evaluating bending, compression parallel or perpendicular-to-grain, or shear strength (Table 1). The number of samples for each test were derived by the WCLIB and were stipulated in their testing plan submitted to the American Lumber Standards Committee (ALSC). Samples were clear of any visible defects such as knots, decay, or wane (bark), and had straight grain. The posts were marked to define areas of clear wood before being bucked to length and then sawn to the specified sizes (Table 1). The samples were conditioned to constant weight at 20^{o}C and 65% relative humidity to a moisture content of approximately 12%.

Table 2.1: Dimensions and replicates of samples used to evaluate material properties of western juniper

Region	**Bending** (25.4 x 25.4 x 406 mm)	**Compression Para.** (50.8 x 50.8 x 203 mm)	**Compression Perp.** (50.8 x 50.8 x 152 mm)	**Shear** (50.8 x 50.8 x 64 mm)
California	50	50	50	50
Idaho	31	31	31	31
Oregon	159	159	159	159

2.1.1 Dry/Green Ratio Samples

A green/dry ratio was established to understand the difference in strength properties between green and dry samples. The samples used for the dry/green ratio samples were obtained from 30 unpeeled log sections 600 – 900 mm long that had been end-sealed to retain moisture. The logs were cut in 50.8 x 50.8 mm (2 x 2 in.) squares that were either 300 or 120 mm long. These pieces were then cut in half. One half was tested in the green condition, while the other half was conditioned to a moisture content of approximately 12% before testing. The conditioned samples were tested in shear or compression. Thirty samples per mechanical test were performed with two halves, creating a total of 120 samples.

2.2 MECHANICAL TEST METHODS

2.2.1 Bending

Three-point bending tests were performed on 25.4 x 25.4 x 406.4 mm long (1 x 1 x 16 in.) juniper beams and this data were used to calculate Modulus of Elasticity (MOE) and Modulus of Rupture (MOR). The tests were conducted on an Instron 5582 universal testing machine with a 100 kN load cell and a round wooden load bearing head connected to the cross arm (Figure 4). The samples were placed in the UTM on a span of 335.6 mm (14 in.) with the tangential surface nearest to the pith facing up so that the load bearing head would come in contact during testing. The samples were loaded at a modified rate of 2 mm/min, which allowed the samples to fail between 5 – 10 min., until failure. The load/deflection curve was recorded. Each failed sample was photographed to record the failure type as described in the ASTM Standard D143. The modulus of elasticity (MOE) and the modulus of rupture (MOR) were calculated using equations 2-1 and 2-2, respectively.

$$MOE = \frac{PL^3}{48ID} \tag{2-1}$$

Where, L is the Span (mm), P is the concentrated center load (N) below the proportional limit, D is the deflection at mid-span (mm) resulting from P, and I is the moment of inertia, a function of the beam's section (width x depth^3)/12

$$MOR = \frac{1.5PL}{bh^2} \tag{2-2}$$

Where, h is depth of the beam, b is the width of the beam, P is the breaking (maximum) load (N), and L is distance between supports/span (mm).

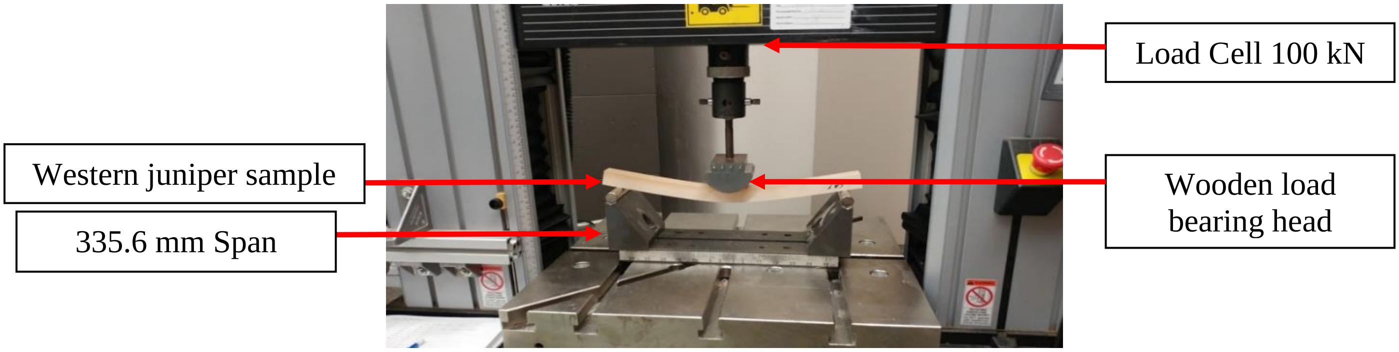

Figure 2.1: Three-Point Bending Test Setup

2.2.2 Compression Parallel

Compression parallel to grain tests were performed on 50.8 x 50.8 x 203.2 mm (2 x 2 x 8 in.) juniper samples on a universal testing machine (MTS) with a 178 kN load cell, using a pivoting base and flat rectangular load bearing head. A pivoting base (Figure 2.2) was used to ensure a uniform distribution of the load to each end of the sample. The cross-arm applied a load at a rate of 1.3 mm/min until significant failure was observed visually. The compressive failure would then be classified under six types of failure as described in ASTM Standard D143. Once the failure type was determined, the maximum load was recorded. The compressive strength of the sample using the maximum load was then calculated using the formula:

$$\textit{Compressive Strength} = \frac{P}{w\,x\,t} \qquad \textbf{(2-3)}$$

Where, *w* is width (mm), *t* is the thickness (mm), and *P* is the breaking load (N).

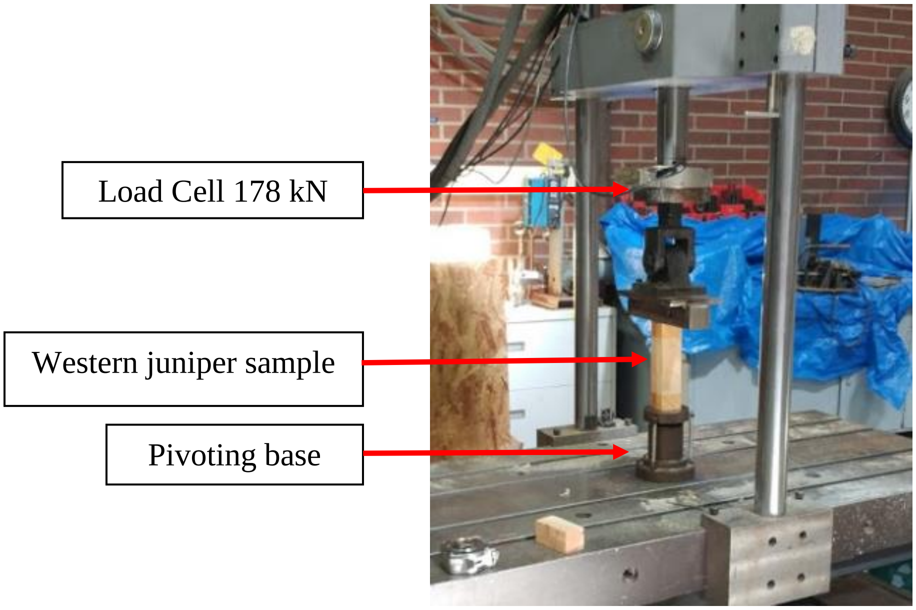

Figure 2.2: Compression parallel-to-grain test setup

2.2.3 Compression perpendicular

Compression perpendicular to grain tests were performed on 50.8 x 50.8 x 152.4 mm (2 x 2 x 6 in.) juniper samples on an Instron 5582 universal testing machine using a 100 kN load cell. A rectangular 50.8 mm wide load bearing plate was attached to the cross-arm. The sample was placed on a steel plate in a position so that the load bearing plate applied a load through a radial surface. The load bearing plate only compressed a 50.8 x 50.8 mm (2 x 2 in.) middle section of the sample (Figure 2.3). The cross-arm was then lowered at a rate of 0.305 mm/min. The test was stopped after an extension of 2.5 mm was reached. Once the test was complete, the area where the sample was compressed was marked and the maximum load was recorded. The load/deflection curve was used to obtain the compressive strength using the load at 1 mm of deflection with the formula:

$$\textit{Compressive Strength} = \frac{P_{1mm}}{L_{sample} \times w_{load\ head}} \qquad \textbf{(2-4)}$$

Where, P_{1mm} is the load at 1 mm, L_{sample} is the length of the sample (mm), and $w_{load\ head}$ is the width of load head (mm).

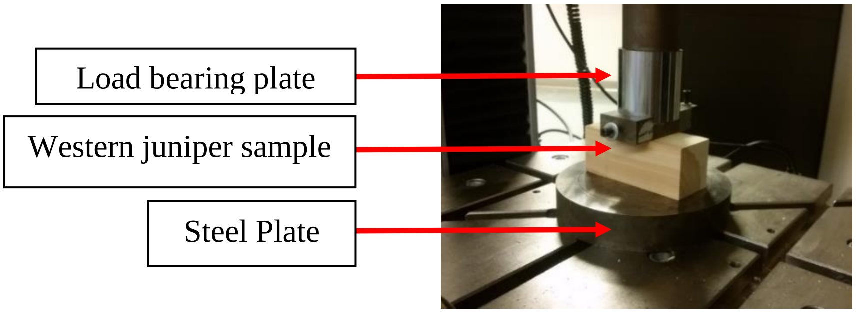

Figure 2.3: Compression perpendicular-to-grain test setup

2.2.4 Shear

Shear tests were performed on 50.8 x 50.8 x 63.5 mm (2 x 2 x 2.5 in.) juniper samples with a 12.7 x 19.05 mm (0.5 x 0.75 in.) notch removed to produce shear failure in the sample. The shear area was calculated by measuring the length and width of the notch. The test was performed on an Instron 5582 universal testing machine using a 100 kN load cell. The setup used a shear tool that applied a force to the area under the notch loaded at a rate of 0.6 mm/min (0.024 in./min) until failure as described in the ASTM D143 standard (Figure 2.4). Maximum force was recorded and shear strength was determined using the equation:

$$\boldsymbol{V = \frac{P}{w_{notch} \times l_{notch}}} \qquad \textbf{(2-5)}$$

Where, P is the maximum force (N), V is the shear strength (MPa), w_{notch} is the width of the block notch (mm), and L_{notch} is the length of the block notch (mm).

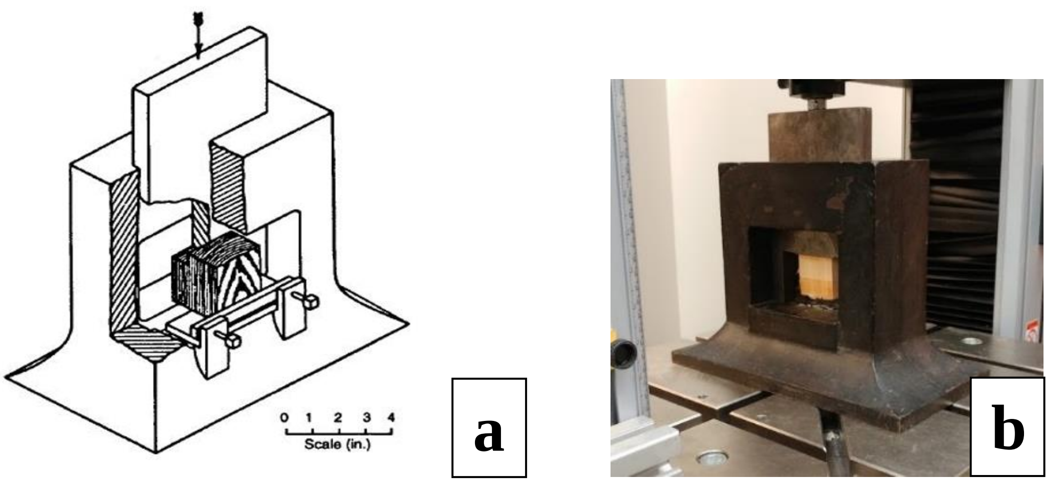

Figure 2.4: Shear Test Setup. (a) Shear apparatus diagram from ASTM D143. (b) Western juniper shear testing

2.2.5 Moisture Content and density

Moisture content and specific gravity were calculated following the ASTM standards D4442 Method B and D2395 Method A, respectively. Each test sample used a 25.4 x 25.4 x 50.8 mm (1 x 1 x 2 in.) section cut from the mechanical sample. For bending, a 25.4 x 25.4 x 25.4 mm (1 x 1 x 1 in.) sample was cut from the end of the beam. The samples were weighed (nearest 0.001 g) to obtain a green weight and then oven-dried at 103°C for 24 hours before being weighed again. The dimensions were measured using calipers (nearest 0.1 mm). Moisture content and density were calculated using the formulas:

$$\boldsymbol{MC\% = \frac{Mass_{Green} - Mass_{Oven\ Dry}}{Mass_{Oven\ Dry}} \times 100} \tag{2-6}$$

$$\boldsymbol{Density = \frac{Mass_{Oven\ Dry} \times 1000}{(width \times depth \times length)_{Oven\ Dry}}} \tag{2-7}$$

2.2.6 Dry/Green Ratio

Once the mechanical testing was completed in shear and compression perpendicular-to-grain, their strength and MC averages were recorded. The green average (x_{green}) and the dry average (x_{dry}) for both test were divided to obtain the initial Dry/Green (DG) ratio.

$$\boldsymbol{Initial\ DG = \frac{xdry}{xgreen}} \tag{2-8}$$

The initial DG ratio was then adjusted to12% MC using the fiber saturation point (FSP) of 27% and the average MC of both tests to create an adjustment factor.

$$\boldsymbol{12\%\ MC\ adjustmnet\ factor = \left[\frac{FSP - MC}{FSP - 12}\right]} \tag{2-9}$$

The adjustment factor was applied to the initial DG ratio to create the adjusted DG ratio (DG Ratio’).

$$\boldsymbol{DG\ Ratio' = \frac{Initial\ DG\ Ratio}{(12\%\ MC\ adjustment\ factor)}} \tag{2-10}$$

These ratios were then used in creating design values for the shear and compression perpendicular-to-grain.

2.2.7 Design Value Calculations

To calculate design values, the data for each mechanical property underwent a multistep process using equations from the ASTM standards D245 and D1990. The procedures for MOR and compression parallel-to-grain were the same, while the other three properties used different procedures. Several factors were applied to the strength properties varying from moisture content adjustments to volume adjustments. Below are the factors that were used in calculating the design values.

The seasoning factor adjusted the moisture content for each sample strength property to a 15% MC:

$$S2 = S1 + \left[\frac{S1 - B1}{B2 - M1}\right](M1 - M2) \qquad \textbf{(2-11)}$$

Where, *M1* is the moisture content at testing (%), *M2* is the moisture content of 15% (%),

S1 is the strength property at *M1* (MPa), *S2* is the strength property at 15% MC (MPa), *B1* and *B2* are Constants: MOR (*B1*=2415, *B2*=40) and Ultimate Compressive Stress (USC) (*B1*=1400, *B2*=34).

The 5% exclusion limit was calculated by finding the 5th percentile using the formula:

$$X = \mu - Z\sigma \qquad \textbf{(2-12)}$$

Where, *X* is the 5th Percentile (5% exclusion limit), μ is the average, *Z* represents 1.645, which is the corresponding value for the 5th percentile, and σ is the standard deviation.

A size factor was used to account for the testing dimensions compared to lumber dimensions, which was done using the formula:

$$F = \left(\frac{ds}{d}\right)^{1/9} \qquad \textbf{(2-13)}$$

Where, *F* is a size factor, *ds* is the sample depth, and *d* is the net surface depth

A volume adjustment factor was used on the values depending on the different grade dimensions to account for different dimensions within a lumber grade, using the formula:

$$F2 = F1\left(\frac{W1}{W2}\right)^{w}\left(\frac{L1}{L2}\right)^{l} \qquad \textbf{(2-14)}$$

Where, *F1* is the property value at volume 1, *F2* is the property value at volume 2, *W1* is the width at *F1*, *W2* is the width at *F2*, *L1* is the length at *F1*, *L2* is the length at *F2*, *w* is a constant for width: (MOR=0.29, UCS=0.13, MOE=0), and *l* is a constant for length: (MOR=0.14, UCS & MOE=0)

Strength ratio factors were observed from ASTM Standard D245, sections 4.1.6 and 4.2.3 note 2, for compression perpendicular-to-grain and shear. The strength ratio factors for the other properties were calculated by the West Coast Lumber Inspection Bureau (WCLIB) (Table 2).

Table 2.2: Factors from the ASTM Standard D245 and the WCLIB

Strength Ratio Factors					
Grade	**Comp para***	**MOR***	**MOE***	**Comp perp**	**Shear para**
SS	0.69	0.65	1.00	1.00	0.50
No. 1	0.62	0.55	1.00	1.00	0.50
No. 2	0.52	0.45	0.90	1.00	0.50
No. 3	0.30	0.26	0.81	1.00	0.50
Stud	0.30	0.26	0.81	1.00	0.50
Construction	0.56	0.34	0.85	1.00	0.50
Standard	0.46	0.19	0.77	1.00	0.50
Utility	0.30	0.09	0.72	1.00	0.50
Other factors					
Reduction factor	1.90	2.10	0.94	1.67	2.10
Seasoning factor	Eq. 11	Eq. 11	Eq. 11	1.08	1.50

* Strength ratios calculated by the WCLIB

The reduction factors were obtained from ASTM Standard D245, section 6.2 and table 8, while the seasoning factors for compression perpendicular-to-grain and shear were obtained from ASTM Standard D245, section 7.1 and table 10 (ASTM Standard D245 2011). The step-by-step process for calculating design values for each property can be seen in Table 3.

Table 2.3: Step-by-step process used to calculate design values of different wood properties

Steps to Calculate Design Values					
Steps	**Comp para**	**MOR**	**Comp perp**	**Shear para**	**MOE**
1	Seasoning Factor	Seasoning Factor	Total Average	5%EL average	Total average
2	5%EL average	5%EL average	DG ratio	DG ratio	Strength Ratio
3	Size factor	Size factor	12% DG adjustment	12% DG adjustment	Reduction factor
4	Strength Ratio	Strength Ratio	Strength ratio	Strength ratio	x
5	reduction factor	reduction factor	Seasoning factor	Seasoning factor	x
6	Volume adjustment factor	Volume adjustment factor	reduction factor	reduction factor	x

2.2.8 Statistical Analysis of Mechanical Tests

The data were analyzed in RStudio (ver. R 3.2.2) using a one-way Analysis of Variance (ANOVA) test and a Tukey-Kramer test to determine if there were differences between locations in the mechanical tests. The assumptions of these tests were verified using a Shapiro-Wilk test to evaluate normality and a Fligner-Killeen test to evaluate equal variance at $\alpha = 0.05$. These statistical tests were performed on MOR, compression parallel-to-grain, and shear tests. Due to violating the assumption for equal variance, the MOE and compression perpendicular-to-grain tests were analyzed using a Kruskal-Wallis test.

The one-way ANOVA test compared the sample means between the locations to determine if sample means are significantly different from each other. Locations were further analyzed using a Tukey-Kramer test multiple comparison procedure.

The Kruskal-Wallis test is a non-parametric test method, which is a common alternative to a one-way ANOVA when assumptions are violated. This method ranks the strength values from highest to lowest in all the locations and uses the ranks in a one-way analysis of variance to tell if there is any significant difference between the locations. The kruskalmc, which is a modified Kruskal-Wallis test, was used to identify differences between groups (Siegel and Castellan 1988).

2.3 DURABILITY MATERIALS AND METHODS

2.3.1 Marine Durability Samples

Samples for the marine durability testing were cut to dimension of 50.8 x 76.2 x 443 mm (1 x 3 x 17.5 in.) and labeled with aluminum tags. The test followed the AWPA Standard E5-15 standard field test for evaluation of wood preservatives to be used in marine applications (uc5a, uc5b, uc5c); panel and block tests. Holes were drilled into the top and bottom of each sample, and these holes were used to secure samples to plastic test racks with a weight on one end and a retrieval rope on the other. A total of 12 samples were examined. The racks were placed into a test site in Newport, OR (Figure 2.5). The samples were examined for evidence of marine borer damage at one year intervals. The samples were first rated visually for any surface attack using a rating system 0-10 with 10 meaning no attack and 0 meaning severe attack resulting in complete destruction. The surfaces were probed with a sharpened awl to detect effects of softening. The cross-sectional area was examined to determine if any marine borers were present. Analysis of these samples will continue until the samples are destroyed.

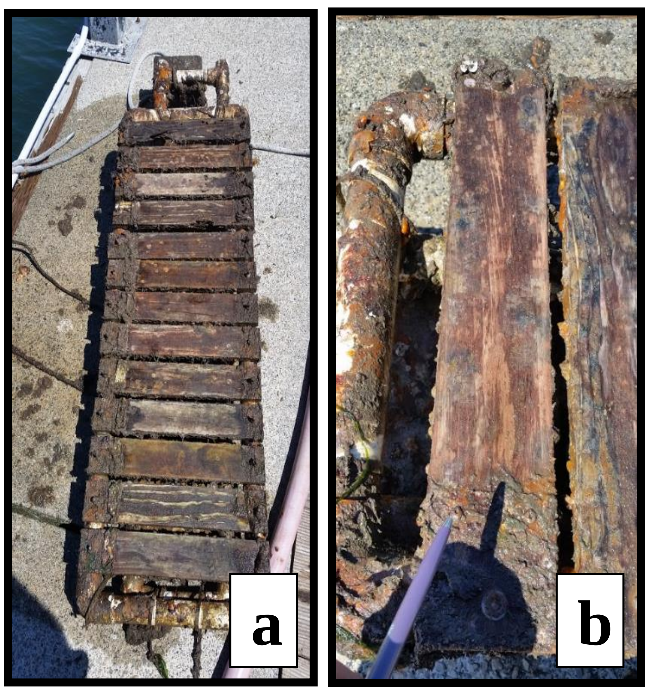

Figure 2.5: Example of a (a) Marine borer test racks. (b) and a western juniper sample attacked by marine borers (6-month exposure).

2.3.2 Laboratory Decay Test

Cubes (19 mm cubes) (370 juniper blocks) were cut from the western juniper material to produce 74 blocks geographic source location. The blocks were oven-dried (103 C) and weighed (nearest 0.001 g). The blocks were soaked with water for 30 minutes prior to being sterilized by exposure to 2.5 mrad of ionizing radiation.

Decay chambers were prepared by half filling the 454 ml bottles with moist forest loam and placing a western hemlock feeder strip on the soil surface. The bottles were then loosely capped and autoclaved for 45 minutes at 121 C. After cooling, the bottles were inoculated with 3 mm diameter malt agar disks cut from the actively growing edges of cultures of the test fungi. The fungi evaluated in these procedures were *Gloeophyllum trabeum* (Pers.ex. Fr.) Murr. (Isolate # Madison 617) (Fries) or *Trametes versicolor* (L. ex Fr.) Pilát (Isolate # R-105). The first fungus produces brown rot while the other species causes white rot. The agar plugs were placed on the edges of the wood feeder strips, then the jars were loosely capped (to allow air exchange), and incubated until the feeder strip was thoroughly covered with fungal mycelium. The sterile test blocks were then placed on the surfaces of the feeder strips, the bottles were loosely capped and incubated at 28 C for 16 weeks (Figure 2.6). Blocks from each treatment group were also established in chambers without a test fungus to establish procedural mass losses with each material. Untreated southern pine sapwood blocks were similarly tested to provide a decay susceptible material to evaluate the rigor of the test procedure. At the end of the incubation period, the blocks were removed, scraped clean of adhering mycelium and weighed to determine wet weight. The blocks were then oven dried (103 C) and weighed. The difference between initial and final oven-dry weight was used as a measure of the decay resistance of each material, using the formula:

$$\boldsymbol{Mass\ Loss}\ \% = \frac{(\boldsymbol{OD_{Before\ Inoculation}} - \boldsymbol{OD_{After\ 16\ incubation}})}{\boldsymbol{OD_{Before\ Inoculation}}} \qquad \textbf{(2-15)}$$

Where, $OD_{Before\ inoculation}$ is the oven dry weight before inoculation and $OD_{After\ 16\ incubation}$ is the oven dry weight after the 16-week incubation period

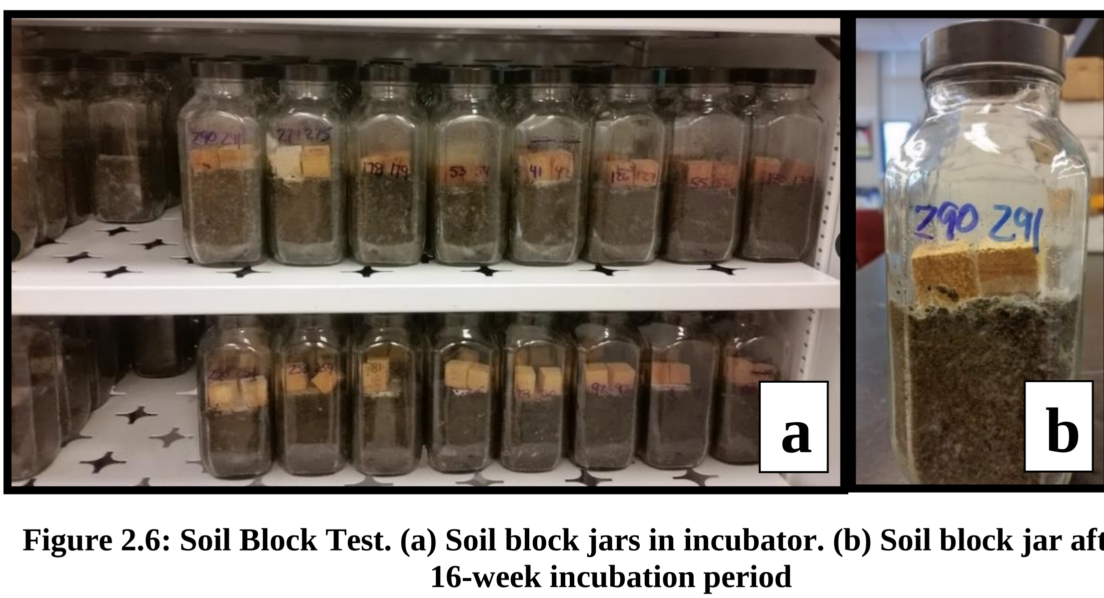

Figure 2.6: Soil Block Test. (a) Soil block jars in incubator. (b) Soil block jar after 16-week incubation period

2.3.3 Ground Contact Test

Posts 101 x 101 x 1219 mm long (4 x 4 in.) were cut from the general sample material. The test followed the AWPA Standard E8-15 standard field test for evaluation of wood preservatives to be used in ground contact (uc4a, uc4b, uc4c); post test. Fifteen posts were cut from each of the five sites to produce a total of 75 posts. The test site (post farm) is located at Peavy Arboretum, about 11 km north of Corvallis, OR (Fig. 10) (Morrell et. al. 1991). The posts were randomly placed into 762 (2.5 ft.) mm deep holes 0.6 m (2 ft.) apart from one another (Figure 2.7). The post placements were recorded with the site location (Table 4). The posts will be analyzed periodically, but results will take much longer to develop. Previous studies showed that split juniper posts had an average service life of 50 years.

Figure 2.7: Ground contact samples at the Peavy test site

Table 2.4: Arrangement of Posts at the Field Test Site by Sample Location and Legend

Test Site Map of Post Locations																
O	I	O	C	P	O	P	P	C	O	B	B	O	C	I	I	P
O	B	C	I	O	P	B	B	C	P	B	B	B	O	I	C	P
C	B	O	P	B	B	C	P	B	I	I	C	I	C	O	E	B
I	C	O	P	I	I	C	I	O	P	O	P	B	P	C	I	O
C	O	P	I	B	P	I	O	C	E	E	E	E	E	E	E	E

Legend of Site Map					
Klamath	**Burns**	**Prineville**	**Idaho**	**California**	**Empty**
O	B	P	I	C	E

3.0 RESULTS AND DISCUSSION

Results of all tests are summarized and presented in Table 5 along with the observed coefficient of variation for each property within each location. Average values across all 5 sites are also presented in Table 5.

Table 3.1: Mean Strength Properties of Western Juniper Samples from Five Locations in the Growing Region

Mean Strength Properties (MPa)						
Means	**Burns**	**Klamath**	**Prineville**	**California**	**Idaho**	**Average**
Comp|| **COV (%)**	27.30 11	32.58 10	28.63 10	30.41 11	26.86 12	29.35 13
Comp⊥ **COV (%)**	5.99 29	5.91 25	6.26 31	5.44 29	4.64 28	5.73 30
Shear **COV (%)**	5.96 17	7.27 17	8.00 14	7.70 15	8.24 19	7.35 47
MOE **COV (%)**	3561.37 29	4629.80 16	3744.20 18	4603.64 25	2739.28 17	3948.48 27
MOR **COV (%)**	57.17 13	60.59 15	61.57 12	57.03 15	53.92 13	58.44 14

Table 6 compares average strength properties for western juniper with similar wood species or species used in construction. The table also includes data from Burke (2008).

Table 3.2: Comparison Between Mean Strength Properties and Specific Gravity of Western Juniper and Similar Wood Species.

Mean strength properties (MPa)									
	Western juniper		**Western redcedar**	**Eastern redcedar**	**incense cedar**	**P.O. cedar**	**Eastern Hemlock**	**Ponderosa pine**	**Douglas-Fir**
	Current Study	**Burke Study**							
Comp||	29.35	35.65	31.40	41.50	35.90	43.10	37.30	36.70	51.20
Comp⊥	5.73	X	3.20	6.30	4.10	5.00	4.50	4.00	5.20
Shear	7.35	8.83	3.20	6.30	4.10	5.00	7.30	7.80	8.90
MOE	3948.48	4915.96	7700.00	6067.39	7170.55	8894.24	8300.00	8900.00	12600.00
MOR	58.44	64.49	51.71	60.67	55.16	64.81	61.00	65.00	87.00
SG @ 12%	0.40	0.39	0.32	0.47	0.37	0.43	0.40	0.40	0.50

Source: Burke 2008, USDA 2010

3.1 COMPRESSION PARALLEL-TO -GRAIN (||) TEST

Compressive strength || for samples from all locations averaged 29.35 MPa with a COV of 13% (Table 5). The highest compressive strength was observed in samples procured from Klamath (32.85 MPa and COV=10%), while the lowest compressive strength was observed in samples from Idaho (26.86 MPa and COV = 12%) (Table 5). There was evidence that mean compressive strength of western juniper varied significantly with location (ANOVA, p-value < .0001). Compressive strength in samples from the Klamath and California locations were significantly greater than those from the other locations (p-values < .05).

Compression || failures in western juniper were similar to those found with other wood species, with cell wall buckling under the applied stress. The common failure types can be seen in Fig.12 with a comparative illustration from ASTM Standard D143 showing failure types. Many samples developed a crushing band where buckling occurred. The majority of samples failed in shear as defined is ASTM Standard D 143 (2014). In shearing, the crushing band had an angle of 45 degrees or greater with the top of the sample (Fig. 12). Crushing and wedge split failure types were also observed.

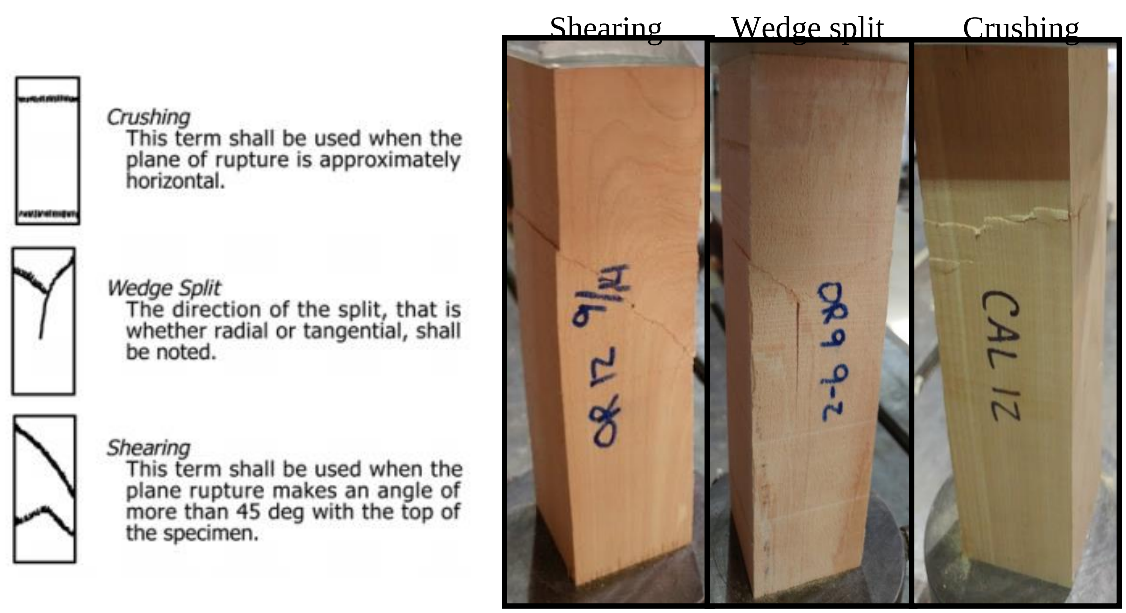

Figure 3.1: Examples of compression parallel-to-grain failures shown as diagrams of common failure types (ASTM Standard D143) or as actual samples from the current test (b) Shearing failure (c) Wedge split failure (d) Crushing failure

Mean compressive strength of western juniper was lower than other similar wood species such as western and eastern redcedar (Table 6) (USDA, 2010). Compression|| tends to be correlated with specific gravity (SG) of a wood species (USDA, 2010), but western juniper had lower compressive strength than species with lower Specific gravity (SG).

Decreased compressive strength could be due to the tracheid diameters of western juniper, which are smaller than most softwoods but equivalent to the diameter of most hardwoods (Myers et al 1998). Hardwoods have been shown to have lower compressive strength in the parallel-to-grain direction than softwoods (USDA, 2010). Western juniper wood also has a fairly uniform tracheid cell wall thickness. The growth rings have only a very narrow band of denser latewood and this uniformity may have also affected load capacity (USDA, 2010).

Differences in compression strength|| could also result from the climate where the trees were grown. This could be due to more competition in the stand due to increased stand density as well as precipitation of the stand. The relationships between average rainfall, snowfall, and elevations and compressive strength were examined by county where the samples were collected. These data must be viewed with caution since microclimate can vary widely, even in a relatively close proximity (Table 7). All the samples grew in areas with similar elevations, but precipitation varied widely.

Moisture influences both quantity and quality of wood produced. Lower precipitation has obvious effects on the number of tracheids produced and lumen diameter. The pattern of precipitation may also affect wood quality (Drew et al 2012). For example, snowfall may be more conducive to steady growth because it would allow for more controlled water release into the soil.

The Idaho site received the lowest average precipitation in terms of rain and snow and materials from this area also had significantly lower compression parallel-to-grain strength than those from the Oregon sites, which all received more precipitation as either snow or rain. Samples from the California site had compressive strengths that did not differ significantly from either Oregon or Idaho samples, although the area received the highest precipitation of the five wood sources. The inconsistent relationship between precipitation and strength illustrates the difficulty in using weather data collected from a single site to characterize a broader geographic area. Precipitation can vary widely in relatively small areas and can vary widely over time. This makes it difficult to use average data for comparative purposes.

Table 3.3: Average Rainfall, Snowfall, and Elevation for Counties Where Western Juniper was Collected.

Annual Average Climate Data					
	Burns (Harney)	**Prineville (Crook)**	**Klamath (Lake)**	**California (Modoc)**	**Idaho (Owyhee)**
Rainfall (cm)	27.74	30.99	25.91	39.55	19.30
Snowfall (cm)	44.55	104.01	111.28	120.29	9.91
Elevation (m)	1478.58	1328.01	1563.62	1516.08	1457.25

Source of Data: National Climatic Data Center (NOAA)

3.2 COMPRESSION PERPENDICULAR-TO-GRAIN (⊥) TEST

Mean compressive strength⊥ for all locations was approximately 5.73 MPa with a COV of 30% (Table 5). The highest compressive strength was observed in samples from Prineville (6.26 MPa; COV = 26%), while the lowest compressive strength was observed in the samples from Idaho (4.64 MPa, COV = 28%) (Table 5). There was statistical evidence that the mean compressive strength of western juniper differed significantly between locations (Kruskal-Wallis, p-value < .0001). There was no significant difference in compressive strength⊥ in samples from Prineville, Burns, Klamath, or California locations. The compressive strength of samples from Idaho did not differ significantly from those from California, but were significantly different from the Oregon locations. Mean compressive strength was highest in samples from Prineville, averaging 6.26 MPa. Materials from this site also had the highest SG (0.43). The lowest mean SG (0.38) was found in samples from Burns, but these samples had the second highest mean compressive strength (5.99 MPa). Again, strength differences could vary due to the high COV%. Samples from the Idaho location were also highly variable since the COV% of SG was 14%, while COV's for samples from the other locations were between 7% and 8%.

During a compression ⊥ test, load is applied laterally to the tracheids. This load collapses the cell walls, and once this happens, the compressive stress starts to plateau. Once the tracheids are fully crushed, the load begins to increase again. This makes it difficult to obtain a maximum force (Ali et al. 2014). As a result, failure in compression⊥ does not cause a break within the wood, but rather deformation of the loaded area. The common failure is a crushed area under the load head that varies in depth (Figure 14). For this reason, compressive strength was calculated using the force at 1 mm deflection as described in ASTM Standard D143.

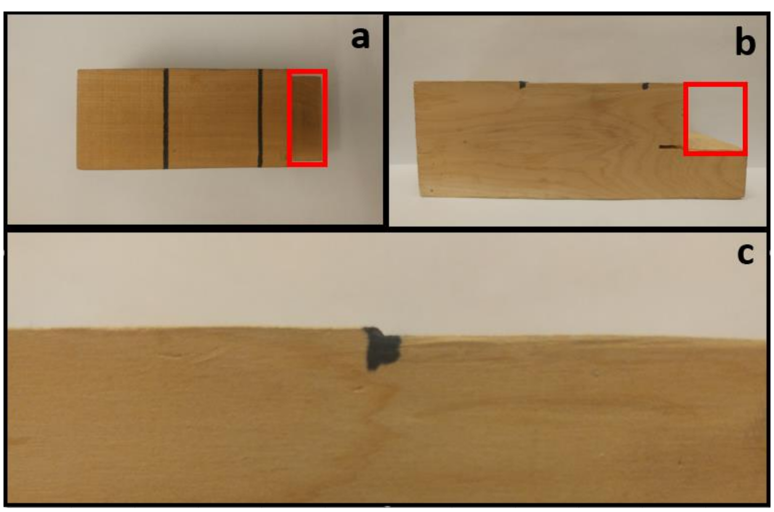

Figure 3.2: Compression perpendicular-to-grain failure highlighted with black sharpie. (a) Top view of sample (b) side view of sample (c) close-up of deformation at failure. *The red boxes represent sections taken for MC% and SG calculations

Compressive strength of western juniper was greater than that reported for western redcedar and incense cedar which have compressive strengths of 3.2 and 4.10 MPa, but somewhat lower than eastern redcedar which has a reported compressive strength of 6.30 MPa (Table 6). Compressive strength is generally correlated with SG (USDA 2010). However, compressive strength of western juniper was higher than Port-Orford-cedar, which has a compressive strength of 5 MPa in the perpendicular direction and a SG of 0.43. The COV for compressive strength⊥ was 30%. Typically, compression⊥ has the highest variability among all the measurable properties. Typical variability for compressive strength⊥ is 28% (USDA 2010). The variability observed for juniper (30%) was slightly higher than the typical values. The unique growth of western juniper made it challenging to obtain perfectly oriented samples and some tests may have been performed on samples that were not at a 90 degree angle to the load direction.

Compression ⊥ of western juniper was higher than that reported for many softwood species used in structural applications, such as Douglas-fir and ponderosa pine (Table 6). High compressive strength could be due to the smaller tracheid diameter in western juniper. These uncharacteristically smaller tracheid diameters are similar to the fibers found in diffuse porous hardwoods (Meyers et al. 1998). Consequently, the compressive strength⊥ might be similar to that found in hardwood species. Hardwoods typically have higher compressive strength in the perpendicular direction than softwoods (USDA, 2010). The second factor that could have contributed to the increase in strength is the lignin content. Western juniper contains an average of 35.5%, which is the highest lignin content of any domestic softwood or hardwood (Meyers et al. 1998). Lignin is considered the bonding agent between cellulose and hemicellulose within the cell wall. Additionally, lignin may enhance polymer interactions that increase cell rigidity (Shmulsky and Jones 2011). These two factors may have produced a higher yield strength thereby increasing tracheids resistance to collapse. These factors could also explain the high compressive strength found in eastern redcedar, which also has smaller diameter tracheids (2.15 mm).

3.3 SHEAR BLOCK TEST

Mean shear strength for samples from all locations was approximately 7.35 MPa (COV=19%) (Table 5). Samples with the highest shear strength originated in Idaho with a strength of 8.24 MPa (COV=19%), while the lowest shear strength of 5.96 MPa (COV= 17%) was observed in samples from Burns, OR (Table 5). There was evidence that the mean shear strength of western juniper varied due to location (ANOVA, p-value < .0001). Samples from Idaho, Prineville, and California did not differ significantly in shear strength (Tukey, p-values > 0.05). Shear strength in samples from the Klamath and California locations did not differ significantly (Tukey, p-values = 0.35), but there was evidence that samples from Klamath differ significantly from those from Idaho and Prineville (Tukey, p-values < 0.05). The shear strength in samples from Burns were the lowest and were significantly different from all others (Tukey, p-values < 0.05) (Figure 15).

Shear failures parallel-to-grain in the radial direction tended to occur along the grain orientation in western juniper. Failure occurred in shear when a compressive force was placed on to the shear block shelf. The section of the block that contained the shelf was not supported on the bottom causing a shear force to occur and the shelf to shear off.

Shear strength of western juniper was greater than that reported for western redcedar and incense cedar, which had shear strengths of 6.83 and 6.10 MPa, respectively, but lower than eastern redcedar which had a reported shear strength of 6.3 MPa (Table 6). Eastern redcedar had the highest SG, while those for the other species were similar or lower. Shear strength tends to be correlated with SG of the species, which can be seen when comparing juniper to the other similar species (USDA, 2010).

Mean shear strength was highest in samples from Idaho, averaging 8.24 MPa (Table 6). This was interesting because other properties in samples from the Idaho location tended to be lower. Shear strength of the samples from Idaho was similar to that for some Douglas-fir samples (coastal = 7.8 MPa and interior west =8.9 MPa) (USDA, 2010). Higher shear strength in Idaho samples could be due to the smaller tracheid diameter, results from the lower precipitation affecting the number and size of tracheids (Drew et al 2012). The smaller tracheids in the Idaho samples could be acting similarly to the fibers in diffuse porous hardwoods, which typically have higher shear strength than softwoods (USDA, 2010). Another factor that could affect properties was the position in the stem where the samples originated. Samples nearer to the pith would tend to contain higher percentages of juvenile wood which generally has lower strength properties than wood formed later (Shmulsky and Jones 2011). However, Idaho samples mainly contained sapwood suggesting that they were taken further out from the pith. Samples from the other locations contained either all heartwood or had some amount of heartwood within them. The small diameter of western juniper could increase the chance that a sample containing mainly heartwood would have some percentage of juvenile wood. The materials from most sites were cut by the cooperators making it difficult to determine the origin. Samples obtained nearer to the pith increases the likelihood of containing a larger percentage of juvenile wood. Juvenile wood is present in all wood species and becomes part of the average properties for that species.

3.4 THREE-POINT BENDING TEST

3.4.1 Modulus of Elasticity (MOE)

Mean Modulus of Elasticity (MOE) for samples from all locations was 3948.48 MPa (COV=27%) (Table 5). Samples with the highest MOE were obtained from Klamath with an MOE of 4629.30 MPa (COV=16%), while the lowest MOE was found in samples from Idaho with an MOE of 2739.28 MPa (COV=17%) (Table 5). There was evidence that mean MOEs of the western juniper varied significantly with location (ANOVA, p-value < .0001). MOEs of samples from Klamath and California were significantly greater than those from the other locations (Tukey, p-values < 0.05). MOEs of samples from Prineville and Burns were significantly different from all other locations (Tukey, p-values < 0.05). MOE's of samples from Idaho were significantly different from all locations (Tukey, p-values < 0.05).

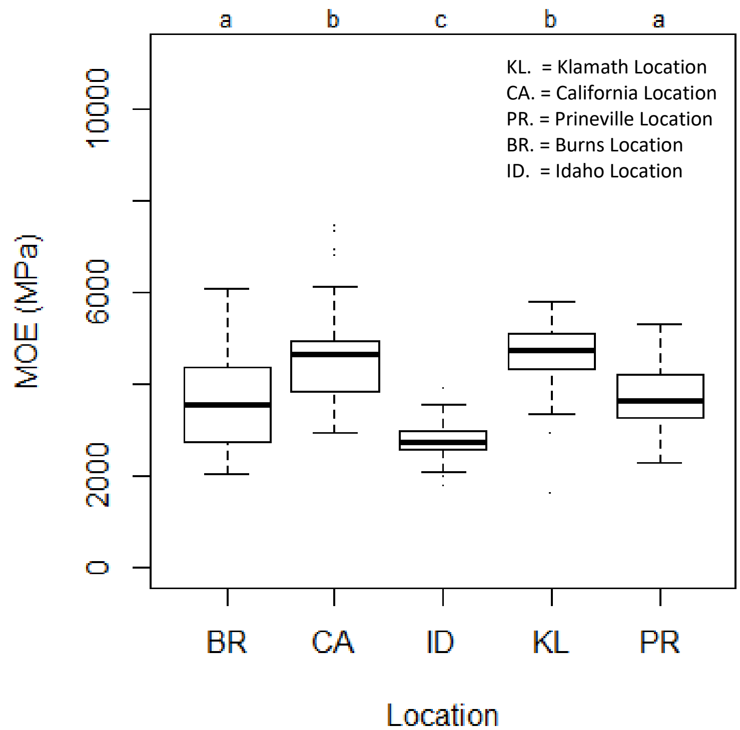

Figure 3.3: MOE of western juniper lumber obtained from five locations in the growing region. Values followed by the same letter(s) do not differ significantly by a Kruskalmc Test

Mean MOE of western juniper samples was significantly lower than those for all of the comparator wood species (Table 6). MOEs of other wood species similar to western juniper ranged between 7000 and 8900 MPa. As described earlier, the low mean MOE of the western juniper samples may be attributed to tracheid length and diameter, but further characterization of the anatomical differences between samples will be required.

Western juniper tracheids average 1.6 mm in length, while tracheids in most other softwoods range from 3 to 4 mm (Myers et al. 1998). Shorter tracheids in western juniper could behave similarly to juvenile wood, which has tracheids that are 3 to 4 times shorter than mature wood, and is associated with 15% to 50% decrease in mechanical properties (Shmulsky and Jones 2011). Western juniper tracheid diameters range from 0.012 to 0.031 mm which is also smaller than those for most softwoods (Myers *et al.* 1998). Tracheid length and diameter tend to be positively correlated with increased MOE (r^2 = 0.684 and r^2 = 0.678) (Kiaei et al. 2013). The lower MOEs in western juniper may be explained by cell dimensions. The decreased mean MOE of the samples from Idaho (2739.28 MPa) may be due to the effects of lower precipitation in this area on tracheid length and diameter.

Two studies should be conducted to further understand the cause for the low MOE of western juniper. The first study should examine the microfibril angles of the secondary cell wall to determine if any differences are related to strength properties. Higher microfibril angles are significantly correlated with reduced MOE's ($r^2 = 0.63$) (Via *et al.* 2009). The second study that should determine cellulose, hemicellulose, and lignin levels in the secondary cell wall layers. Western juniper has unusually high amounts lignin, and low cellulose and hemicellulose content compared to other softwood species. These variations may relate to the lower properties observed with this species. It is important to note that both of these studies would be costly and may not be justified for the potential applications for this species.

3.4.2 Modulus of Rupture (MOR)

Mean Modulus of Rupture (MOR) for samples from all locations was 58.44 MPa (COV=14%) (Table 5). Samples with the highest MOR originated in Prineville with a MOR of 61.57 MPa (COV=12%), while the lowest MOR was found in samples from Idaho (53.92 MPa) (Table 5). There was evidence that mean MOR of the western juniper varied significantly with location (ANOVA, p-value < .0001). MOR of samples from Prineville and Klamath did not differ significantly (Tukey, p-value = 0.95), nor did those from Klamath, Burns, or California (Tukey, p-values > 0.05). The MOR of samples from Idaho did not differ from those from Burns or California (Tukey, p-values > 0.05), but differed significantly from those from Prineville and Klamath (Tukey, p-value < 0.05).

The three-point bending test flexes a sample to failure and uses the maximum load to calculate MOR. The failure modes of the test samples were typical for bending tests with failure in tension that leads to shear. These failure modes are typical of those described in ASTM Standard D143.

Mean MOR of western juniper was similar to that found with other species such as western redcedar and incense cedar (Table 6). MOR tends to be correlated with SG, and western juniper followed this pattern (USDA 2010). Mean MOR of western juniper did not deviate from the other species as much as the MOE, and this may again, be explained by cell wall characterizations. MOR is strongly correlated with tracheid diameter (r2=0.08), but is poorly correlated with tracheid length (r2=0.47) (Kiaei et al. 2013). MOE is influenced by both the length and diameter of the tracheids as stated above.

3.5 GREEN/DRY RATIO OF COMPRESSION PERPENDICULAR-TO-GRAIN AND SHEAR

Green compressive strength of western juniper averaged 4.14 MPa, while dry compressive strength had a mean of 4.85 MPa. The initial dry/green ratio for the compressive strength was 1.21 and adjusting this ratio for 12% moisture content produced a value of 1.30 (Table 8).

The green shear strength of western juniper had a mean of 6.21 MPa, while dry shear strength had a mean of 7.70 MPa. The initial dry/green ratio for the shear strength was 1.24 and adjusting this ratio for 12% moisture content produced a value 1.68 (Table 8).

Table 3.4: The Dry/Green Ratios for Compressive and Shear Strength of western juniper samples collected from five areas within the growing range

Green/Dry Ratios of Compressive and Shear Strength (MPa)				
	Compression		Shear	
	Dry	*Green*	*Dry*	*Green*
Mean	4.85	4.14	7.70	6.21
StanDev	1.45	0.85	1.68	1.15
Max	8.23	6.03	12.06	8.90
Min	1.32	2.49	5.09	4.25
COV%	30%	20%	22%	18%
Ratio	1.18		1.24	
Adjusted Ratio	1.30		1.68	

Compression and shear strengths for dry western juniper were similar to the first samples tested. The results for green samples were lower than those for dry samples, for both tests, as expected due to the effect of increasing moisture content above the fiber saturation point (FSP) on wood properties. Green samples exceeded the FSP of 27% for this species. Wood above the FSP has lower stiffness and strength due to the effects of water on cellulose in the cell wall. Moisture absorbed by wood below the FSP is chemically bound to the wood via hydrogen bonding. These bonds weaken microfibril interactions, reducing wood properties (Shmulsky and Jones 2011).

3.6 STRENGTH VALUES

Calculated strength values in the current study differed from those found by Burke (2008). MOE was 20% lower, while MOR was 9% lower than those found by Burke (2008). Differences between strength could have resulted from sample site selection, tree selection, or load-rate. Sample sites from the Burke (2008) work were similar to those in this study, excluding the Idaho site. Excluding the shear values, samples from Idaho had the lowest average for all other properties. These lower values reduced the overall averages. The trees in the Burke study were specifically selected for stem form, height, diameter, and crown morphology, with no defects, while this study used materials that were randomly selected from commercial products (Burke 2008). Unfortunately, Burke did not provide specific methods that could be compared with those in the current study.

3.7 DESIGN VALUES

The test results were used to calculate base design values for all combined locations of western juniper strength and presented in Table 3.5.

Table 3.5: Base design values for various grades of western juniper lumber using data obtained from different areas of the growing region

	Base Design Values (MPa)				
Grade	**Comp ||**	**MOE**	**MOR**	**Comp ⊥**	**Shear**
SS	6.59	3582.50	6.46	3.68	0.86
No. 1	5.92	3582.50	5.46	3.68	0.86
No. 2	4.96	3224.25	4.47	3.68	0.86
No. 3	2.86	2883.91	2.58	3.68	0.86
Stud	3.14	2883.91	3.50	3.68	0.86
Construction	6.22	3027.21	5.09	3.68	0.86
Standard	5.11	2758.52	2.84	3.68	0.86
Utility	3.33	2579.40	1.35	3.68	0.86

An example of the process for creating design values is illustrated below, for MOR and MOE:

The MOR values were first adjusted to 15% MC by applying a MC factor (Eq. 2-11). The MC adjusted values were averaged to calculate the 5% exclusion limit (Eq. 2-12) and this value was then adjusted from a 25.4 mm thickness to an 88.9 mm thickness (Eq. 2-13), the typical lumber dimension. A strength ratio factor was applied to determine values for each of the 8 grades (Table 5). A reduction factor was applied to account for the load duration and safety factors (Table 5). The last step developing the design values for MOR was to adjust for the volume of each grade (Eq. 14), as strength may vary by dimensions.

Average values were used for MOE design values, because design is based on strength rather than stiffness. A strength ratio factor was applied to the average based on the lumber grade (Table 2), then a reduction factor was applied to account for load duration and safety (Table 3). These factors are property dependent.

The design values are being presented to American Lumber Standards Committee in their July 2017 meeting to be considered for possible publication in National Design Specification 2018.

3.8 LABORATORY DECAY TEST

Southern pine sapwood samples exposed to *Trametes versicolor* experienced average weight losses of 32.15%, while those exposed to *Gloeophyllum trabeum* experienced average weight losses of 42.55% (Table 10). *T. versicolor* produced little decay over the 16-week exposure in the juniper soil block test. Average weight losses ranged from 0.30% in samples from Idaho to 1.72% in samples from Burns (Table 10) (Figure 3.4). Weight losses in the non-fungal inoculated controls were similar to the *T. versicolor* inoculated samples, indicating little to no attack on the inoculated samples. Western juniper inoculated with *T. versicolor* indicated high resistance compared to southern pine sapwood, which averaged 32.15% weight loss (Table 10).

Table 3.6: Mass Loss of Western Juniper Heartwood Samples from Locations in the Growing Area as Determined by Exposure to Decay Fungi – an AWPA E10 Soil Block Test (a)

Mean Weight Loss Percent (%)				
Species	**Wood Source**	**Rot Fungi**		
		T. versicolor	***G. trabeum***	***Controls***
W. juniper	***Burns***	1.63 (0.5)	1.51 (1.7)	2.30 (0.7)
W. juniper	***California***	1.04 (0.7)	11.06 (19.4)	0.96 (1.1)
W. juniper	***Idaho***	0.30 (0.9)	7.95 (8.3)	0.89 (0.3)
W. juniper	***Klamath***	1.72 (1.5)	2.85 (1.8)	1.48 (0.1)
W. juniper	***Prineville***	1.50 (0.8)	4.09 (4.7)	1.49 (0.3)
S. Pine	**-**	32.15 (9.4)	42.55 (25.2)	-0.32 (0.2)

(a) Values represent means of samples sites and values in (parentheses) are SD.

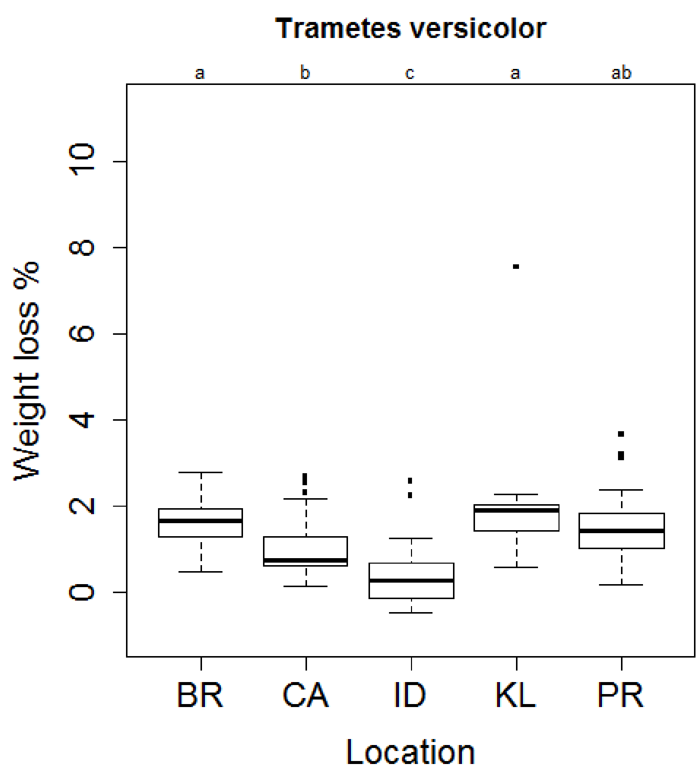

Figure 3.4: Percent weight losses of western juniper lumber obtained from five locations in the growing regions and exposed to T. versicolor in an AWPA E10 soil block tests. Values followed by the same letter(s) do not differ significantly by a Kruskalmc Test

T. versicolor is a white-rot fungus that can decay all wood components uniformly (Zabel and Morrell 1992). Western juniper's heartwood was highly resistant to attack. The most abundant extractive in western juniper heartwood is cedrol, which is a sesquiterpenoid (Myers et al. 1998). High cedrol levels in western juniper contribute to its antifungal properties and this compound is effective against white-rot fungi, including *T. versicolor* (Tumen *et al*. 2013).

G. trabeum, produced some decay over the 16-week exposure in the soil block test. Average weight losses ranged from 2% in samples from Burns to 11% in samples from California (Table 10) (Figure 3.5). Weight loss in the non-fungal inoculated controls were lower than some of *G. trabeum* inoculated samples, indicating some attack on the inoculated sample, but weight losses were still in the highly decay resistant range. Western juniper inoculated with *G. trabeum* indicated high resistance compared to southern pine sapwood, which averaged 42.55% weight loss (Table 10)

G.trabeum is a brown-rot fungus that decomposes the cell-wall carbohydrates and leaves a modified lignin. Western juniper heartwood was more sensitive to *G. trabeum* compared to *T. versicolor*. The soil block samples exposed to *G.trabeum* had a total mean weight loss of 6%. Cedrol has been shown to be less effective against brown-rot fungi (Tumen *et al*. 2013).

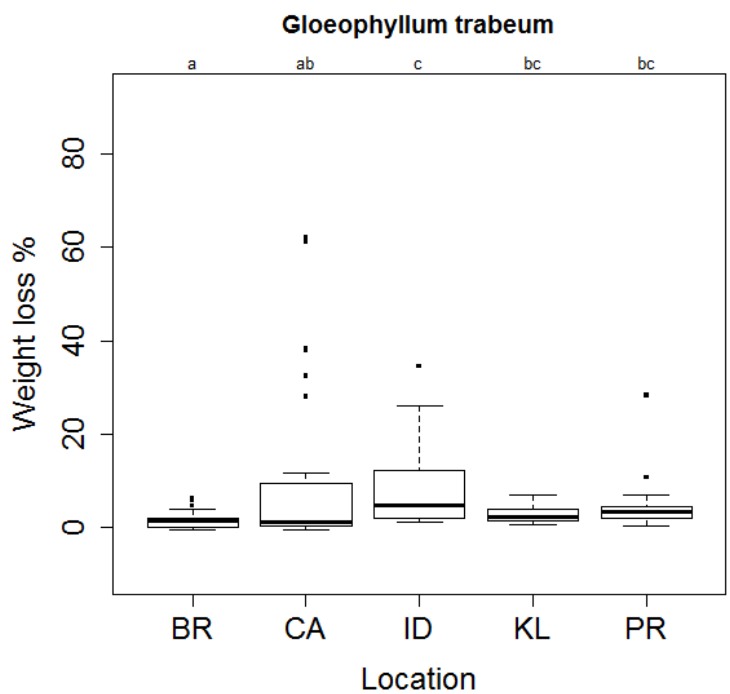

Figure 3.5: Percent weight losses of western juniper lumber obtained from four locations in the growing regions and exposed to G. trabeum, in an AWPA E10 soil block tests. Values followed by the same letter(s) do not differ significantly by a Kruskalmc Test.

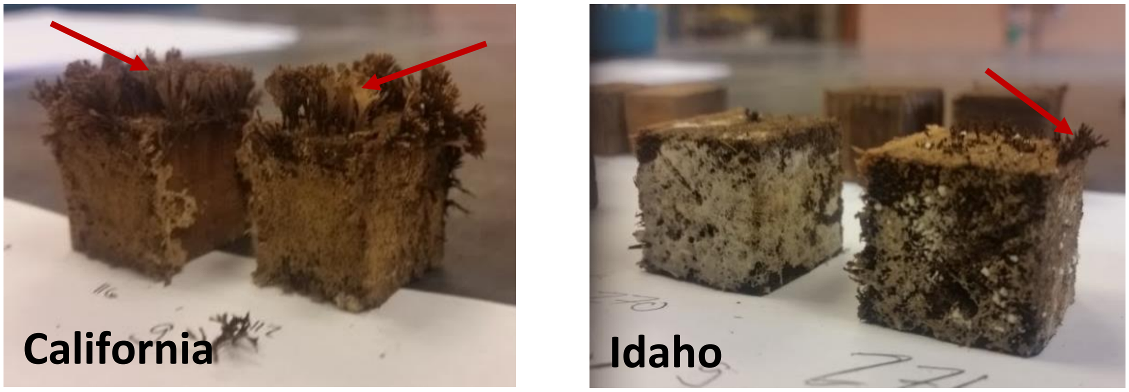

Figure 3.6: Outliers from the California and Idaho locations that were exposed to Gloephyllum trabeum in an AWPA E10 soil block test. Blocks contain fruiting bodies on the surface (arrows)

There were a number of outliers in the blocks from the California and Idaho locations exposed to G. trabeum, with weight losses between 30% and 65%. These outliers also contained fruiting bodies on the surface of the western juniper blocks (Figure 3.6). High weight losses with G. trabeum could be attributed to the presence of included sapwood. Included sapwood or white ring, is less resistant to decay and termite attack, than the heartwood that surrounds it (Taylor 2003). Variability between and within heartwood also affects the decay resistance (Freitag and Morrell 2001; Ajuong et al. 2014). The variability could be a contributor, since the outliers in the California location all came from the same post and section of the tree.

The American Society for Testing and Materials Standard D-2017 uses weight loss in a soil block test as a measure of durability and lists the criteria for various decay resistance classes as follows:

0-10 %	Highly resistant
11-24	Resistant
25-44 %	Moderately resistant
>45 %	Slightly or non-resistant

The *T. versicolor* and *G. trabeum* samples for western juniper had averages of 1% and 6% weight loss, which falls under the category of highly resistant to both brown and white-rot fungi.

4.0 CONCLUSIONS

This study conducted tests on western juniper to assess its mechanical property and durability attributes. Four mechanical tests were performed on western juniper samples, compression parallel-to-grain, compression perpendicular-to-grain, shear parallel-to-grain, and bending. Sub-samples were cut in compression perpendicular-to-grain and shear parallel-to-grain tests to obtain green/dry ratios for western juniper. Three different durability tests were conducted on western juniper, which included a marine borer test, laboratory decay test, and ground contact test. The marine borer and ground contact tests were long-term studies and are still on going.

Mechanical properties of juniper showed some variability within location from where the samples were procured. The compression ⊥, shear, and MOR properties appeared to be similar or higher when compared to other similar softwood species. The compression || and MOE properties were significantly lower than those of similar species. The cause behind the variability in strength could be attributed to the anatomy and chemical makeup of western juniper. The short tracheids could cause the low MOE values, while small diameter of tracheids could have affected the other strength properties. The chemical compounds and the fact that juniper has a very high lignin content, may have caused the tracheids to become more rigid giving it higher compressive strength in the perpendicular-to-grain direction.

The samples from Idaho tend to have significantly different properties than the other locations and this could be due to the climatic conditions around the site. It has been shown that drought like conditions have an effect on the anatomy of softwoods, which could explain the Idaho location values. The Klamath and Prineville locations consistently had the highest strength values out of the other locations and both had similar climatic conditions.

The design values of western juniper were established and will be presented to American Lumber Standards Committee for inclusion in National Design Specification 2018. This effort of inclusion of design values in the NDS is spearheaded by West Coast Lumber Inspection Bureau. With the inclusion of western juniper in the NDS, it would give the option for it to be used in government funded construction projects. The adaptation of western juniper in the NDS could provide engineer with another option when deciding material for the project.

The laboratory decay test showed western juniper was both brown and white-rot resistant. The soil blocks that were used in the decay test had an average range of 0% to 6% weight loss, and the ASTM Standard D 2017 states any wood species having an average weight loss below 10% is considered highly decay resistant. The high decay resistant properties can be attributed to the high amounts of chemical compounds. The high amounts of cedrol deterred the white-rot fungi, while the combination of cedrol and lignin deterred the brown-rot fungi. The observations on the marine borer and ground contact tests had shown no signs of attack within the evaluations done thus far after one year of exposure.

After evaluation of strength and durability attributes of western juniper, this species has shown to have some beneficial properties that could be utilized. High decay resistance of the heartwood of western juniper could allow this species to be used as a substitute for some treated wood applications.

In conclusion, western juniper would be considered as a prominent naturally durable wood substitute for non-structural applications. It could be applicable into certain structural applications, but special consideration should be taken in to account for the lower strength values.

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