TECHNICAL NOTE

Shrinkage and Static Bending Properties of *Juniperus scopulorum* from the Rocky Mountains

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Abstract

Juniperus scopulorum is a common tree in the lower elevations of the Rocky Mountains, and is often removed in restoration treatments. This work reports on selected mechanical and physical properties of *J. scopulorum*. Ten trees were felled and processed, and a static bending machine was used to test 162 specimens. Additionally, 82 ovendried specimens were assessed for shrinkage and density. Results show an air-dry modulus of elasticity (MOE) of 4,611 MPa, air-dry modulus of rupture (MOR) of 68,460 kPa, green MOE of 3,846 MPa, green MOR of 46,760 kPa, specific gravity of 0.4184 (green basis), and shrinkage value of 7.956 percent. These numbers suggest several new uses for the wood including highway signage, guardrails, and bioenergy feedstock.

Rocky Mountain juniper (*Juniperus scopulorum*) is widely distributed throughout the North American west. *J. scopulorum,* as well as *osteosperma* and *monosperma,* often occur as a companion to piñon pine (*Pinus edulis*) in the Rocky Mountain region's extensive piñon–juniper woodlands (Romme et al. 2009). The piñon–juniper forest type is believed to be drastically expanding its range and is the target of many restoration projects. Restoration treatments are often achieved by mastication, which limits utilization of the waste material to biomass or fiber products. However, whole-tree removal is also conducted on smaller projects, on sites with sensitive soils, and in culturally sensitive areas (Tausch et al. 2009). Firewood has traditionally been the most common use for the wood and continues to be in modern times (Ffolliott et al. 1999). Juniper also makes excellent post material, because the extractives in the wood provide for natural decay resistance; tests indicate that untreated southwestern juniper posts can give over 50 years of service (Barger and Ffolliott 1972).

The mechanical properties of hundreds of species from around the world have previously been reported in the literature (Markwardt and Wilson 1935; Alden 1995, 1997; Kretschmann 2010; Niklas and Spatz 2010). This knowledge base has allowed for the creation of reliable standards and building codes relating to wood utilization, as well as inspired innovative new wood products. Thus far, little is known about properties of *J. scopulorum,* and the species is not generally considered desirable in the wood products industry. However, the Rocky Mountain region has been turning to increasingly smaller-diameter trees to feed mills (Hayes et al. 2007). Many of these trees are harvested in restoration or fire mitigation projects, and utilization of the by-products can reduce waste and potentially provide a cost offset. Thus, there may be an opportunity for increased juniper utilization if the wood has suitable properties.

This study is meant to address gaps in the literature by providing selected properties of *J. scopulorum* including modulus of elasticity (MOE), modulus of rupture (MOR), specific gravity, and shrinkage. Hazen Research, Inc. (unpublished data, 2003) conducted some of the only available *J. scopulorum* tests when they investigated its chemical composition and combustion values. They report that the air-dried wood has a higher heating value of 19.59 MJ/kg (8,430 BTU/lb). The need to know other properties of the species has been expressed in the literature. Air-dry strength and stiffness values have been identified as essential knowledge to guide the production of posts, poles, and ties (Barger and Ffolliott 1972). Several studies have demonstrated the need to know mechanical properties of green wood (Coder 2005, Duryea et al. 2007, Niklas and Spatz 2010, Tomczak et al. 2011). Among other things, knowledge of green strength and stiffness can help urban

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foresters predict how a tree will cope with forces from wind, snow, and gravity. Specific gravity values of juniper wood will be useful in formulating biomass conversions (Chojnacky and Moisen 1993), understanding a tree's resistance to xylem cavitation (Hacke et al. 2001), and assessing its suitability for use in wood–plastic composites (Clemons and Stark 2007). In this article, these property values are provided along with discussions of how findings may guide future utilization of this common Rocky Mountain species.

Materials and Methods

Sample collection and preparation

Sample preparation was guided by ASTM D143-09 (ASTM International 2009), a widely used standard for testing mechanical properties of small clear timber specimens. An alternative would have been ASTM D198-15 (ASTM International 2015), which describes similar tests for structural lumber. However, the former was chosen for two reasons: (1) Kretschmann (2010) cites ASTM D143 as being the primary testing standard used to determine static bending properties, and (2) the most likely end use of *J. scopulorum* is not in structural lumber. ASTM D5536-94 (ASTM International 2010) describes methods of tree selection and processing to prepare samples used in ASTM D143-09 (2009). The random sampling method was chosen because it is appropriate for tests meant to establish general allowable lumber stresses for a particular species. The nature of juniper trees presented several challenges in obtaining knot-free specimens of sufficient size. For this reason, the secondary test method in ASTM D5536-94 (2010) was followed. This method calls for specimens with a cross section of 2.54 by 2.54 cm (1 by 1 in.), and a length of 40.64 cm (16 in.).

Trees were harvested from Ben Delatour Scout Ranch, located in the Red Feather Lakes area of northern Colorado. The site sits at 2,286 m (7,500 ft) in elevation and consists of rolling hills stocked with ponderosa pine (*Pinus ponderosa*) and other tree species. The area receives an average of 46.7 cm (18.4 in.) of precipitation annually and year-round average temperatures range from –1.6°C to 10.9°C (29.2°F to 51.7°F; Red Feather Lakes Colorado 2014). Ten *J. scopulorum* trees with diameter at breast height greater than 20.3 cm (8 in.) were harvested. Logs were transported back to the Colorado State Forest Service headquarters and soaked with water to keep them green until milling. A small bandmill was used to mill the logs into flitches of 7.62 cm (3 in.) or smaller width, so they could be further processed with a table saw and jointer. Half of the flitches were kept in water tanks to ensure they stayed green, and half were stacked to air-dry.

Flitches were processed into 2.54 by 2.54 by 40.64-cm (1 by 1 by 16-in.) specimens (sticks) at the Colorado State University Industrial Sciences Laboratory. Flitches were edged on a jointer and cut to within 0.159 cm (1/16 in.) of target size on a table saw. Care was taken to prepare sticks that were free of knots and other defects, but that was not always possible when working with this material. If specimens failed at knots during testing, the test was dropped and excluded from calculations. Green sticks were kept submerged in water to prevent loss of moisture. Air-dried flitches were left stacked for 3 months to dry to an approximate moisture content of 12 to 16 percent and then stored outside after processing.

Testing and data collection

Static bending tests.—Static bending tests were conducted in accordance with ASTM D143-09 (2009). Testing was done in a climate-conditioned room at 20°C (68°F). Relative humidity of the room was not recorded, but was kept constant by the air-conditioning unit. Moisture content of air-dry sticks was recorded immediately before testing using an electronic moisture meter, to ensure that they were in the acceptable range of 12 to 16 percent. In total, 87 air-dry specimens and 75 green specimens were tested.

A 900 series universal testing machine, manufactured by Applied Test Systems, was used to conduct the tests. The span length was 36 cm (14 in.), and each end of the sample was supported on a bearing plate mounted on a knife edge to permit lateral rotation. Specimens were placed so that the load was applied to the tangential surface nearest the pith. Machine speed was 0.13 cm (0.05 in.) per minute. The testing machine displayed the pressure in pounds exerted on the specimen at any given time. Additionally, a digital gauge attached to a plunger displayed the specimen's deflection. Readings (pounds of pressure) were taken at 0.13-cm (0.05-in.) increments between 0.13 and 0.51 cm (0.2 in.) and later used to calculate MOE. The range in load at specimen failure was 182.3 to 324.1 kg (401.8 to 714.6 lb), mean 255.0 kg (562.1 lb) for air-dry specimens and 118.0 to 273.0 kg (260.1 to 601.8 lb), mean 174.1 kg (383.9 lb) for green specimens.

Specific gravity and shrinkage tests.—Guidance for specific gravity testing came from ASTM D2395-14 (ASTM International 2014). After being used in static bending tests, green specimens were cut into 2.54 by 2.54 by 7.62-cm (1 by 1 by 3-in.) blocks. Both volume and weight of specimens were recorded before and after oven-drying at 103°C. Volume was measured using the water immersion method (ASTM International 2014); ovendried samples were first placed in a paraffin bath to seal them. The density of water (1 g/cm^3) was used to convert wood density to specific gravity. The following equations were used:

$$\mathrm{SG_G} = (\mathrm{WT_{OD}}/\mathrm{Vol_G})/1\,\mathrm{g/cm^3} \tag{1}$$

$$\mathrm{SG_{OD}} = (\mathrm{WT_{OD}}/\mathrm{Vol_{OD}})/1\,\mathrm{g/cm^3} \tag{2}$$

$$\mathrm{Shrinkage}\,(\%) = (\mathrm{Vol_G} - \mathrm{Vol_{OD}})/\mathrm{Vol_G} \times 100 \tag{3}$$

where

$\mathrm{SG_G}$ = green specific gravity,
$\mathrm{SG_{OD}}$ = ovendry specific gravity,
$\mathrm{WT_{OD}}$ = ovendry weight,
$\mathrm{VOL_G}$ = green volume, and
$\mathrm{VOL_{OD}}$ = ovendry volume.

Results and Discussion

Air-dry strength and stiffness

The mean MOE value for air-dry specimens was 4,611 MPa (668,800 psi) and the mean MOR was 68,460 kPa (9,929 psi; Table 1). The test specimens displayed a range in moisture content of 11.4 to 14.9 percent (mean, 13.0%). However, despite the range in moisture content, the overall coefficient of variation (CV) for both tests was lower than

Table 1.—Air-dry strength and stiffness summary results for 87 samples.[a]

	Mean value	Min.	Max.	SD	CV (%)	95% confidence interval bound
MOE	4,611 MPa	3,496	6,197	688.6	14.9	144.7
	(668,800 psi)	(507,100)	(898,800)	(99,870)	14.9	(20,990)
MOR	68,460 kPa	45,930	87,150	8,111	11.9	1,714
	(9,929 psi)	(6,661)	(12,640)	(1,183)	11.9	(248.6)

[a] Range in moisture content for specimens was 11.4 to 14.9 percent and the mean was 13.0 percent. CV = coefficient of variation; MOE = modulus of elasticity; MOR = modulus of rupture.

the 50 species average CVs of MOE (22%) and MOR (16%) reported in the *Wood Handbook* (Kretschmann 2010).

The air-dry MOE values for *J. scopulorum* are low compared with other commercial softwoods in the Rocky Mountains, which may preclude the species from various structural applications. However, *J. scopulorum* is unlikely to be used in structural applications because of its small diameter and prevalence of knots. The low stiffness value does reduce the wood's chances for use in products such as tool handles, an application for which it would otherwise be highly suitable. On the other hand, *J. scopulorum* has a high air-dry MOR relative to other commercial softwoods in Colorado. For comparison, the following air-dry values are reported in Kretschmann (2010): ponderosa pine MOE of 8,900 MPa (1.29×10^6 psi) and MOR of 65,000 kPa (9,400 psi) and Douglas-fir MOE of 12,600 MPa (1.83×10^6 psi) and MOR of 87,000 kPa (12,600 psi).

The ideal use for the wood would be one that takes advantage of its flexibility, strength, and natural decay resistance. One such use would be in highway materials such as guardrails and signposts. In these, a low MOE may be desirable so that it may reduce the impact borne by vehicles in collisions (Burke 2001). Faller et al. (2009) tested the suitability of ponderosa pine and Douglas-fir as posts supporting steel W-beam guardrails. They found that the material performed well and recommended that other species be tested to provide more outlets for wood from small-diameter thinning projects. There is certainly a market for this in Colorado; Lynch and Mackes (2001) reported that Colorado highways used over 3.5 million new board feet of combined highway signage and guardrail posts in the year 1997.

Green strength and stiffness

The mean MOE value for green specimens was 3,846 MPa (557,900 psi) and the mean MOR was 46,760 kPa (6,782 psi; Table 2). These results have implications on trees in urban settings. High green MOR values suggest that in general *J. scopulorum* trees are better suited to handle high levels of wind and snow loading than species with lower values. A more accurate, site-specific evaluation can be made using knowledge of a tree's elastic limit. Coder (2005) describes a nondestructive process where a winch is used to apply force to a tree and evaluate the wind load that the tree could withstand before breakage. The elastic limit of a species can be calculated from its MOE and maximum crushing strength.

Specific gravity and shrinkage

The mean specific gravity for the test specimens was 0.4545 (ovendry basis) and 0.4184 (green basis), and the mean volumetric shrinkage value was 7.956 percent (Table 3). The shrinkage tests had very high variance relative to the other tests in this study. According to Glass and Zelinka (2010), the average coefficient of variability for volumetric shrinkage in wood is approximately 15 percent, but in these tests it was 26 percent. One possible explanation for this is the irregular growth rings exhibited by the specimens. Although the specimens were all approximately the same size, their distance in the tangential direction varied. Because of the anisotropic nature of wood, one would expect a specimen with shorter tangential distances (end grain with parallel growth rings) to shrink less than one with longer tangential distances (end grain with curved growth rings).

Usage of juniper biomass (bioenergy feedstock, animal bedding, mulch, etc.) would be consistent with restoration projects that involve mastication. Specific gravity is positively correlated with biomass yield (Chave et al. 2005), so results of this study suggest that the wood could be suitable for these uses. Additionally, the higher heating

Table 2.—Green strength and stiffness summary results for 75 samples.[a]

	Mean value	Min.	Max.	SD	CV (%)	95% confidence interval bound
MOE	3,846 MPa	2,826	5,213	512.9	13.3	116.1
	(557,900 psi)	(409,800)	(756,100)	(74,390)	13.3	(16,840)
MOR	46,760 kPa	36,700	64,120	5,849	12.5	1,324
	(6,782 psi)	(5,323)	(9,300)	(848.3)	12.5	(192.0)

[a] CV = coefficient of variation; MOE = modulus of elasticity; MOR = modulus of rupture.

Table 3.—Specific gravity (SG) and shrinkage results for 82 samples.[a]

	Mean value	Min.	Max.	SD	CV (%)	95% confidence interval bound
SG (green)	0.4184	0.3657	0.5413	0.03506	8.4	0.007589
SG (oven-dry)	0.4545	0.3943	0.5786	0.03660	8.1	0.007922
Shrinkage	7.956%	3.935%	15.63%	2.099%	26.4	0.4543

[a] CV = coefficient of variation.

value of *J. scopulorum* (19.59 MJ/kg, 8,430 BTU/lb) is within the normal ranges used in bioenergy processes reported by Wright et al. (2009). To estimate the total biomass yield that a specific project or region could produce, total wood volume and specific gravity are necessary. Much work has gone into equations to predict the aboveground volume in juniper trees of all species (Chojnacky 1985). Chojnacky and Moisen (1993) extended this work to provide formulas for converting total juniper volume to biomass using specific gravity. However, the authors did not report the specific gravity of *J. scopulorum*. With values provided by the current study, there is now enough information to estimate large-scale juniper biomass yield.

The density of wood not only influences its external strength, but also the strength of the xylem conduit in living trees. Wood density is positively correlated with resistance to xylem implosion from negative pressure (Hacke et al. 2001), which helps a tree tolerate drought conditions. Hacke et al. (2001) specifically mention that this phenomenon may explain juniper's rapid expansion throughout the west. With density being such an important predictor of drought tolerance, knowledge of density may be useful in developing models to predict future distribution of species taking climate change into account.

Conclusions

Results from this study show that *J. scopulorum* wood, relative to other Rocky Mountain softwoods, has a low MOE, high MOR, low rate of volumetric shrinkage, and high specific gravity. The low MOE potentially limits applications where stiffness is an important factor. However, the wood compensates with its high values for flexibility, strength, and dimensional stability. Additionally, studies have already shown that *J. scopulorum* wood has excellent natural decay resistance and high aesthetic qualities (Ffolliott et al. 1999).

In this study, important strength and stiffness properties of *J. scopulorum* are presented. Other properties are still unknown, such as compression, impact bending, work to maximum load, and more. Additional research is needed for similar juniper species such as *J. osteosperma* and *J. monosperma*. One more opportunity for future research is the benefits or drawbacks of using wood with lower MOE in highway guardrail systems.

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