VOLUME RECOVERY, GRADE YIELD, AND PROPERTIES OF LUMBER FROM YOUNG-GROWTH SITKA SPRUCE AND WESTERN HEMLOCK IN SOUTHEAST ALASKA

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ABSTRACT

Wood volume recovery, lumber grade yield, and mechanical properties of young-growth Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophyla* (Raf.) Sarg.) were examined. The sample included trees from commercially thinned and unthinned stands and fluted western hemlock logs obtained from a sort yard. Mean cubic recovery of lumber volume from all sawn logs was 44.9 percent. More than 90 percent of the lumber was graded as No. 2 or better; about 5 percent was Clear (C-Select or D-Select), and about 10 percent was Select Structural. No differences in volume recovery or grade yield due to thinning were noted for Sitka spruce logs. For western hemlock, more volume was recovered from trees in unthinned stands; more Select Structural and No. 1 lumber and less No. 2 lumber was produced from thinned stands. No differences in volume recovery or grade yield were noted between fluted and unthinned western hemlock. Bending properties were found to be excellent for this resource. All grades for both species exceeded or matched published bending modulus of elasticity (MOE) values for these species. No differences in MOE were noted between thinned and unthinned lumber from both species. Slightly higher MOE values were noted in fluted western hemlock for the No. 1 and No. 2 lumber grades. Lumber from this young-growth resource appears best suited for structural light framing or molding and millwork, based on visual grading rules and mechanical properties observed.

Nearly 1 million acres of timber have been harvested from public and private lands in southeast Alaska since the early 1900s. Natural regeneration has created a young-growth forest that will be merchantable within 40 years. Understanding the lumber product value and economic potential of young-growth timber from the region was identified as a high-priority information need in the Tongass Land Management Plan (17). This knowledge in the context of the manufacturing capabilities within the region will guide timber management decisions and define marketing opportunities in the future.

Previous lumber studies in southeast Alaska on old-growth Sitka spruce (*Picea sitchensis* (Bong.) Carr.) (3,6,12,14) and western hemlock (*Tsuga heterophyla* (Raf.) Sarg.) (3,5,6,20) have become outdated because of technology changes. Lumber recovery and defect studies also have been done in the Pacific Northwest for western hemlock (4,8). No existing studies exist that relate lumber recovery and grade yield to individual tree characteristics for young-growth Sitka spruce

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and western hemlock in southeast Alaska.

In this paper, we describe wood volume recovery, lumber grade yield, and some physical and mechanical properties for commercially thinned and unthinned young-growth Sitka spruce and western hemlock in southeast Alaska. In addition, we examine fluted western hemlock logs. Stem fluting has been reported to reduce product value (10) and it is expected to be prevalent in young, coastal stands throughout the region (11).

METHODS

TREE SELECTION AND MEASUREMENTS

Trees were obtained from two 90-year-old stands that originated after a 1906 fire near Old Franks Creek on Prince of Wales Island, Alaska (55°26'18" N., 132°28'28" W.). These stands were selected for two principal reasons. First, they contained Sitka spruce and western hemlock that typify the young-growth commercial timber base in southeast Alaska in terms of site quality, age, composition, and size. Second, the stands were included in a USDA Forest Service regional stand-density study that contained thinned and unthinned trees **(Table 1).** Each of the two study installations from which logs were obtained consisted of four 1-acre plots — a control and three plots of varying thinning intensity (light, medium, and heavy) that were thinned in 1976 by using spacing and diameter guidelines (2). The sampling procedure was designed to select a sample representative of the variation in both unthinned and thinned treatments, rather than to detect differences in various levels of thinning.

A total of 278 trees were selected, ranging from 8 to 22 inches in diameter at breast height (DBH) in 2-inch diameter classes **(Table 2).** Trees were felled in 1997 by using normal industry practices and bucked into lengths preferred for each species. Each tree and corresponding woods-length logs (14 to 41 ft.) were numbered in the field to uniquely identify plot number, tree number, and location of every log segment within each tree.

Tree measurements included DBH, 16-foot form class, height to the base of the live crown, and total height **(Table 3).** Annual rings were counted at stump height. Log measurements included small-end diameter, length, and taper

TABLE 1. — Characteristics of the stand-density study plots before and after thinning in 1976.

Installation, thinning regime, and plot number	50-year site index	Before thinning: Mean DBH	Density	Basal area	After thinning: Mean DBH	Density	Basal area	Basal area removed
	(ft.)	(in.)	(trees/ac.)	(ft.²/ac.)	(in.)	(trees/ac.)	(ft.²/ac.)	(%)
Old Franks Creek I								
Control (179)	64	3.6	4,444	313	3.6	4,444	313	0
Light (178)	77	4.3	3,583	356	6.9	580	152	57
Medium (180)	79	3.6	4,417	317	7.8	300	100	68
Heavy (177)	100	6.3	1,833	394	9.7	185	95	76
Old Franks Creek II								
Control (184)	123	9.0	750	330	9.0	750	330	0
Light (181)	132	10.9	495	323	14.0	215	228	29
Medium (183)	125	7.5	1,030	318	11.9	190	146	54
Heavy (182)	133	10.3	580	336	17.3	85	138	59

TABLE 2. — Number of trees selected for sawing by diameter class, species, and silvicultural treatment.

Diameter class	Sitka spruce: Unthinned	Sitka spruce: Thinned	Western hemlock: Unthinned	Western hemlock: Thinned	Total
(in.)					
8	11	8	10	9	38
10	11	8	9	11	39
12	9	11	11	10	41
14	10	8	11	10	39
16	10	10	9	10	39
18	13	12	10	11	46
20	5	2	5	8	20
22	7	7	1	1	16
Total	76	66	66	70	278

TABLE 3. — Attributes for sample trees by species and treatment.

Species and treatment	Mean age[a]	Mean DBH	Mean 16-ft. form class	Mean live-crown ratio	Mean total height
	(yr.)	(in.)		(%)	(ft.)
Sitka spruce[b]					
Unthinned	83 (3.8)'	14.5 (4.7)	0.81 (0.14)	29.2 (10.3)	110.8 (20.7)
Thinned	83 (2.8)	14.7 (4.4)	0.77 (0.21)	33.4 (7.2)	98.5 (22.8)
Western hemlock[b]					
Unthinned	84 (4.8)	13.6 (3.8)	0.78 (0.12)	38.5 (9.2)	93.2 (20.9)
Thinned	83 (3.9)	13.9 (4.1)	0.78 (0.18)	45.4 (9.8)	88.6 (17.7)

[a] Age determined at stump height.
[b] Control - trees obtained from stands outside the stand-density study plots.
[c] Values in parentheses are standard deviations.

(Table 4). A sample of 45 woods-length fluted hemlock butt logs was selected from the Smith Cove sort yard; the logs were probably obtained from the Old Franks Creek area **(Table 4).** No tree or stand information was available for these logs. These logs were included to evaluate the effect of fluting on lumber yield and quality.

LOG SCALING AND PROCESSING

Logs were scaled by USDA Forest Service scalers using cubic scaling rules (16) and Scribner scaling rules (15) **(Ta-**

TABLE 4. — Woods-length log attributes by species, treatment, and log position.

Species, treatment, and attribute	Log position 1 (butt log)	2	3
Sitka spruce			
Unthinned			
Mean small-end diameter (in.)	10.1 (3.5)[a]	7.9 (2.1)	6.4 (1.4)
Mean length (ft.)	37.9 (5.3)	33.3 (8.1)	20.3 (6.2)
Mean taper (in./ft.)	0.18 (0.05)	0.10 (0.03)	0.15 (0.03)
Number of logs	76	62	33
Thinned			
Mean small-end diameter (in.)	10.4 (3.8)	8.4 (2.6)	6.5 (1.2)
Mean length (ft.)	37.4 (6.1)	30.9 (7.9)	26.8 (6.3)
Mean taper (in./ft.)	0.17 (0.10)	0.11 (0.03)	0.17 (0.04)
Number of logs	66	50	21
Western hemlock			
Unthinned			
Mean small-end diameter (in.)	9.2 (2.9)	6.8 (1.8)	7.7 (2.0)
Mean length (ft.)	37.6 (4.8)	28.8 (8.3)	11.6(9.1)
Mean taper (in./ft.)	0.15 (0.04)	0.13 (0.03)	0.19 (0.07)
Number of logs	66	50	9
Thinned			
Mean small-end diameter (in.)	9.6 (3.4)	6.9 (2.1)	6.5 (1.2)
Mean length (ft.)	38.3 (4.5)	27.4 (7.5)	25.2 (6.4)
Mean taper (in./ft.)	0.14 (0.04)	0.15 (0.03)	0.20 (0.03)
Number of logs	70	51	7
Fluted (unthinned)			
Mean small-end diameter (in.)	11.4(2.4)	--	--
Mean length (ft.)	29.6 (6.2)	--	--
Mean taper (in./ft.)	0.14 (0.05)	--	--
Number of logs	45	--	--

[a] Values in parentheses are standard deviations.

TABLE 5. — Woods-length cubic and Scribner log scale by species.

Species	Cubic scale Gross	Net	Defect	Scribner scale Gross	Net	Defect
	----- (ft.³) -----		(%)	----- (BF) -----		(%)
Sitka spruce	5,342	5,180	3	22,964	22,710	1
Western hemlock	5,106	4,682	8	20,880	20,030	4
Fluted hemlock	1,148	873	24	5,340	4,650	13
Total	11,596	10,735	7	49,184	47,390	4

TABLE 6.— Mill-length log distrigution by species and silvicultural treatment

Species	Treatment	Number of logs	Small-end diameter mean
			(in.)
Sitka spruce	Unthinned	338	10.9 (3.4)[a]
	Thinned	346	10.9 (3.5)
Westernhemlock	Unthinned	313	10.0 (3.1)
	Thinned	273	10.2 (3.1)
	Fluted	104	11.8 (2.5)
All	All	1,374	10.6 (3.3)

[a] Values in parentheses are standard deviations.

ble 5). Logs were debarked by using a ring-debarker then bucked into mill-length segments. Mill lengths were 9.5 and 12.5 feet for Sitka spruce and 10.5 and 13.5 feet for western hemlock, which included a 6-inch trim allowance. A total of 1,374 mill-length logs were produced from the 278 trees selected, an average of about 5 mill-length logs per tree. Numbers of mill-length logs in the sample and their mean small-end diameters were tabulated by species and thinning treatment (Table 6).

Logs were processed at the Ketchikan Pulp Company Sawmill. The sawmill's objective was to maximize yield of the highest quality export-grade lumber. Material not meeting these standards was chipped for pulp, thereby allowing the mill to produce lumber with minimal wane. The mill is equipped with an end-dogging, quad-band headrig, cant resaw, and two board edgers. A mill so equipped is best suited for sawing small logs. Sawmill workers sawed logs under normal processing conditions and procedures. A Forest Service crew was used to track the identity of each log and piece of lumber as it was manufactured in the sawmill. All study logs were sawn into export-dimension lumber as follows:

Sitka spruce:

1-3/16 by 4-1/8 inch (30 by 105 mm)
1-3/4 by 4-1/8 inch (45 by 105 mm)
4-1/8 by 4-1/8 inch (105 by 105 mm)

Western hemlock

1-3/4 by 3-9/16 inch (45 by 90 mm)
3-9/16 by 3-9/16 inch (90 by 90 mm)

VOLUME RECOVERY

Cubic-foot recovery percentage by species was used as a measure of wood volume yield from logs to lumber. Cubic-foot recovery is the surfaced green cubic-foot volume of lumber divided by gross log cubic volume and is the most accurate representation of lumber-to-log relations (7,19). Total volume recovery and mean volume recovery by species and thinning treatment were determined. Differences in volume recovery by species on account of thinning and fluting were evaluated by using the two-sample t-test (a = 0.05) (21).

LUMBER GRADE YIELD

Surfaced green lumber was graded by using Western Wood Products Association (WWPA) grading rules (18) by a certified WWPA lumber grade inspector. Lumber was graded into the following WWPA lumber grade categories: C-Select or D-Select (Clear), Select Structural, No. 1, No. 2, Utility, and Economy. Each piece of lumber was stamped with a unique number to allow accountability back to the log and tree after evaluation of mechanical properties ofindividual pieces oflumber. Lumber grade yield was described by species, thinning regime, and log position by using Scribner board-foot volume percentage (BF%). Differences in grade yield on account of thinning and fluting were evaluated by species by using the two-sample t-test (a = 0.05) (21).

PHYSICAL AND MECHANICAL PROPERTIES

Specific gravity, moisture content, bending MOE, and modulus of rupture (MOR) values were determined for the sample and compared to values for the traditional resource. All the 2,263 planed and graded square-dimension lumber was tested at the mill nondestructively by using transverse vibration test methods (13) to determine bending MOE. A Metriguard Model 3 10 E-computer was used for these tests. A subsample of this lumber (1 88 pieces) was selected for further testing at the USDA Forest Service's Forest Products Laboratory in Madison, Wisconsin. These pieces were first nondestructively tested in the laboratory by using the identical transverse vibration set-up used in the mill to determine if any changes owing to air-drying may have occurred before or during shipping. Static bending tests were then conducted in accordance with American Society of Testing and Materials D 198 procedures (1). Static bending, MOE, and MOR values were determined for each piece. Specific gravity and moisture content also were determined for sections cut from each piece. Differences in bending MOE due to thinning and fluting were evaluated by species using by the two-sample t-test (a = 0.05) (21).

RESULTS AND DISCUSSION

Thinning forests can profoundly affect species composition, stand structure, rates of growth, and wood characteristics. Increased stem taper is just one expected effect of commercially thinning a stand. Expanding the live crown ratio, where branches grow larger and are retained longer, affects the size of knots. Accelerating stem growth, creating fewer rings per inch, and increasing the rate of branch occlusion also are expected. Together these effects influence recoverable volume and lumber qualities.

TABLE 7. —Mean cubic recovery by species and treatment based on surfaced green lumber as a percentage of total log volume.

Species and treatment	Mean cubic recovery
	(%)
Sitka spruce	
Unthinned	47.0 (13.6)[a]
Thinned	46.4 (12.1)
Western hemlock	
Unthinned	44.5[b] (13.7)
Thinned	41.9 (13.7)
Fluted (unthinned)	42.7 (12.0)
All logs	44.9 (13.3)

[a] Values in parentheses are standard deviations.
[b] Boldface numbers indicate a significant difference between unthinned and thinned treatments ($p < 0.05$).

Trees represented in this study grew from natural regeneration and were thinned as part of an unrelated stand-density study when stems reached commercial size (about age 70). In southeast Alaska, however, thinning is customarily done precommercially before stands reach about 20 years old. Thus the thinned component of our sample may not be representative of the regional lumber resource from precommercially thinned stands.

DEFECT AND VOLUME RECOVERY

The thinned and unthinned trees (excluding the fluted logs) contained a combined net cubic log scale of 9,862 ft.^{3} **(Table 5).** Defect for both species was extremely low, with minor sweep and mechanical damage that occurred during felling and yarding characterizing this defect. The 45 fluted hemlock logs had a net cubic scale of 873 feet^3 and had the greatest amount of log defect with most deduction attributable to excessive fluting. Overall, Sitka spruce had the lowest defect.

Mean cubic-foot recovery percentage was 44.9 for all sawn logs **(Table 7).** This value is slightly lower than results from previous recovery studies in southeast Alaska. Woodfin and Snellgrove (20) found a mean cubic-foot recovery percentage of 48 for rough green lumber from old-growth western hemlock logs. Lane et al. (12) reported a mean cubic-foot recovery percentage of 56 for old-growth Sitka spruce (rough green lumber). This difference can be attributed to the Ketchikan sawmill product objectives and a slight decrease in recovery that occurs when lumber is surfaced. Logs were full-sawn with no wane to maximize volume of the highest grade export lumber rather than to maximize overall volume yield. Had the mill sawn the logs for domestic-grade lumber and to maximize lumber yield, the mean cubic-foot recovery would have been about 15 to 20 percent higher. Once the best lumber was cut from the log, remaining material was chipped.

Differences in volume recovery as a result of thinning were either small or lacking **(Table 7).** Small differences were expected since bucking logs into short lengths substantially reduces the impact of increased taper in logs. Thinning had no effect on volume recovery for Sitka spruce. Western hemlock trees from unthinned stands yielded slightly greater volumes than trees from thinned stands. This may be partially explained by differences in stem shape within the live crown as indicated by a difference in crown ratio **(Table 3).** There was also a difference in the mean small-end diameter of the third log **(Table 4).** Because wane tolerances were minimal, small differences in small-end diameter would have an important effect on the volume of recovered lumber. There was no difference in cubic-foot recovery percentage between fluted and nonfluted western hemlock.

GRADE YIELD

Board-foot volume yield of domestic lumber grades for each species is listed in **Table 8.** For both species, about 92 percent of lumber was graded No. 2 and better. This level of recovery is expected. Efficiently running mills typically produce greater than 90 percent No. 2 and better. In addition, a relatively large percentage met the highest grading

TABLE 8. — Board foot lumber volumes and percent by Western Wood Products Association (WWPA) grade, species, and size.

Species	Thickness	Width	Total volume[a]	WWPA lumber grade: Clear[b]	Select Struc.	No. 1	No. 2	Util.	Econ.
	----- (in.) -----		(BF)	----------------- (%)[c]					-----------------
Sitka spruce	1-3/16	4-1/8	13,667	5.0	7.6	39.1	38.2	5.0	5.1
	1-3/4	4-1/8	10,594	0.8	5.3	39.8	46.8	4.4	2.9
	4-1/8	4-1/8	15,879	12.0	13.5	39.5	27.7	3.7	3.7
Total			40,140	6.7	9.3	39.4	36.3	4.3	4.0
Western hemlock	1-3/4	3-9/16	16,617	2.9	12.4	38.0	39.4	3.5	3.9
	3-9/16	3-9/16	17,171	4.5	8.8	35.0	44.0	5.0	2.6
Total			33,788	3.7	10.6	36.5	41.7	4.3	3.2

[a] Board-foot lumber volumes were calculated by using the following nominal sizes: 1-3/16 by 4-1/8 = 1.25 by 4 inch; 1-3/4 by 4-1/8 = 2 by 4 inch; 4-1/8 by 4-1/8 = 4 by 4 inch; 1-3/4 by 3-9/16 = 2 by 4 inch; 3-9/16 by 3-9/16 = 4 by 4 inch.
[b] Clear includes C-Select and D-Select.
[c] Percentages may not add up to 100 because of rounding.

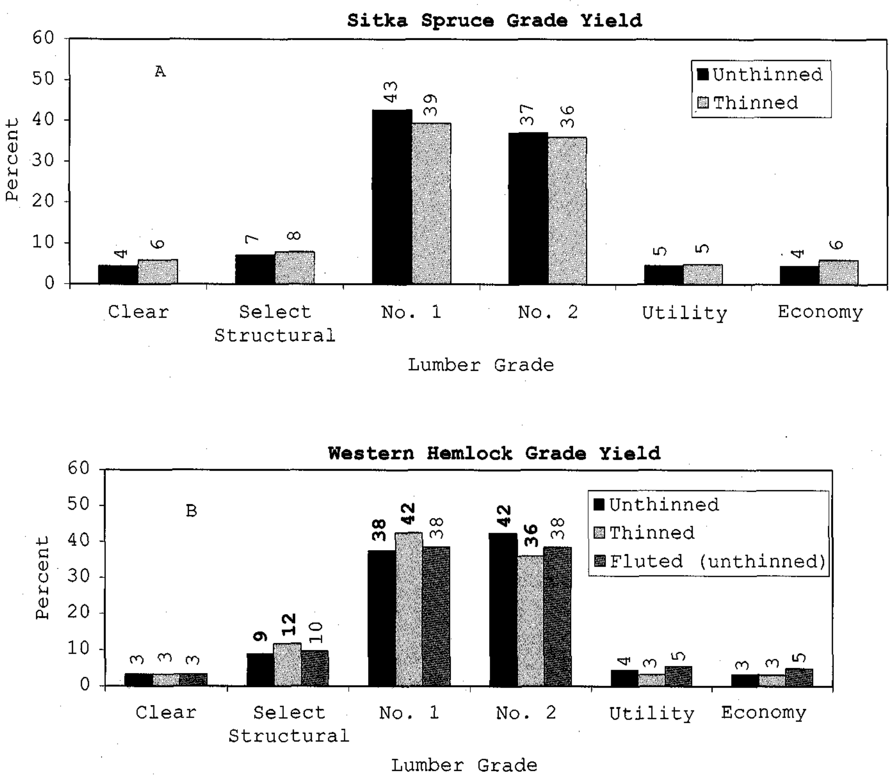

Figure 1.—Percentage of board-foot volume grade yield by species and thinning regime. Grades are according to Western Wood Products Association standards: "Clear" includes C-Select and D-Select. Percentages may not add up to 100 because of rounding. Bold label indicates a significant difference between thinned and unthinned treatments (a = 0.05).

standards: Select Structural (average of 9.9%) and Clear (average of 5.3%). Because lumber was sawn to export dimensions and grade specifications, grade yield could be affected when applying domestic grading rules. A greater percentage of lumber likely was graded No. 2 or better than if it was sawn strictly for domestic products. In addition, only the best material was sawn from each log to make the highest export grade lumber. This undoubtedly produced more high- grade domestic lumber. But, had the sawmill intended to maximize lumber volume (assuming cubic-foot recovery percentage was around 60 percent), clearly a large percentage of lumber would meet No. 2 or better grading standards.

Although thinning had no effect on grade yield in Sitka spruce **(Fig. 1A),** it did affect grade yield in western hemlock **(Fig. 1B).** Thinned western hemlock produced more Select Structural and No. 1 lumber and less No. 2 lumber. Because this stand was thinned after crown closure, we expected that thinning would have a minimal effect on grade yield.

Maintenance of accountability from the tree to sawn pieces made it possible to evaluate grade yield for different log positions **(Table 9).** Generally, log position one is the butt log and (assuming 40-foot log lengths), log position two begins at about 40 feet (plus stump height and trim) of tree height, and so on. Evaluating grade yield by log position allows examination of how relative log height affects grade and the effect of thinning on this relation. Results indicate that thinning had little to no effect on grade yield by relative log position.

It is interesting to note how grade yield changes with tree height. The main effect is manifest in the highest quality grades. As log height increases, percentages of Select Structural and Clear grades decrease. Clear material is produced on larger diameter logs that have long since overgrown branch stubs. As log height increases, log diameter gets smaller and branching frequency increases.

Results of fluted hemlock grade yield for woods-length logs are displayed in **Figure 1.** Fluting had no effect on grade yield compared to unthinned hemlock. About 90 percent of the volume was in No. 2 and better lumber, with about 13 percent being in the highest quality Select Structural and Clear grades.

PHYSICAL AND MECHANICAL PROPERTIES

The bending properties of both the western hemlock and Sitka spruce pieces compare favorably to industry standard values (9) for green material **(Table 10).** Results of the analysis comparing bending MOE values obtained from transverse vibration nondestructive tests conducted in the field and in the laboratory show little or no difference **(Table 10).** Moisture content data summarized in **Table 10** reveal that pieces had not dried appreciably during transit. MOR values observed for lumber from both species was lower than reported clear wood values (9). This difference most likely was due to the presence of knots in the material we tested.

Results of bending MOE testing for each species by lumber grade are summarized in **Table 11.** This analysis indicates that for the highest quality visual grades (Clear and Select Structural), the best quality structural material also is found. Western hemlock bending MOE for all grades exceeded or matched the published bending MOE of 1.3 1 (clear wood basis), thereby indicating this material has potentially superior mechanical properties to other segments of the resource. Similar results were found for Sitka spruce bending MOE values by lumber grade, except No. 2 and Utility grades, which had values slightly lower than the published value of 1.23. No significant differences in bending MOE for material from thinned and unthinned stands were noted for either species. Thinning earlier in the rotation may affect this mechanical property by increasing diameter growth and proportion of juvenile wood. Significantly higher bending MOE values were noted in fluted western hemlock for the No. 1 and No. 2 lumber grades. Overall results of mechanical testing indicate that lumber produced from this young-growth resource is at least as good as the traditional resource in terms of structural properties.

CONCLUSIONS

Lumber sawn from young-growth Sitka spruce and western hemlock in southeast Alaska appears to be best suited for structural light framing or molding and millwork based on visual grading rules and mechanical properties observed. In this study, which applied export standards, more than 90 percent of the lumber was graded as No. 2 or better. Bending properties were found to be excellent for this young-growth resource. All grades for both species matched or exceeded published bending MOE values for these species. Differences in volume recovery, grade yield, and bending MOE due to thinning were either lacking or small. Further research is needed to explore the effects of precommercial thinning on wood quality.

TABLE 9. — Board-foot grade yield by woods-length log position.

Species, treatment, and log position	Board-foot grade yield					
	Clear[a]	Select Struc.	No. 1	No. 2	Util.	Econ.
	(%)[b]					
Sitka spruce						
Unthinned						
Butt log	5.6	8.4	41.7	34.5	5.5	4.3
2nd log	4.2	6.0	42.9	38.6	4.0	4.3
3rd log	1.2	3.9	45.7	40.7	2.6	5.9
Thinned						
Butt log	7.3	10.4	38.7	33.3	4.1	6.3
2nd log	4.4	4.2	42.4	38.0	6.2	5.0
3rd log	3.1	6.0	29.2	48.1	5.1	8.4
Western hemlock						
Unthinned						
Butt log	4.1	10.6	37.4	39.5	4.9	3.4
2nd log	1.6	5.7	38.3	48.1	3.7	2.6
3rd log	0.0	0.0	33.3	52.1	0.0	14.6
Thinned						
Butt log	4.2	12.6	40.2	37.0	3.4	2.6
2nd log	1.2	9.9	41.3	34.5	3.0	4.1
3rd log	0.0	12.5	48.8	32.4	1.0	5.2
Fluted'						
Butt log	3.2	9.6	38.4	38.5	5.5	4.9

[a] Clear includes C-Select and D-Select.
[b] Percentages may not add up to 100 because of rounding.
[c] Fluted logs were from unthinned stands.

TABLE 10. —Forest Products Laboratory static test results by species. Values are means with standard deviations in parentheses.

Species and value source	Number of pieces	Specific gravity	Moisture content	Modulus of elasticity	Modulus of rupture
			(%)	(million psi)	(psi)
Sitka spruce					
Observed value[a]	57	0.38 (0.05)	44	1.44 (0.25)	4,706 (1,051)
Alaska,:				1.38 (0.26)	
FPL_{TV}[c]				1.36 (0.23)	
Wood Handbook value[d]		0.37		1.23	5,700
Western hemlock					
Observed value[a]	131	0.40 (0.04)	61	1.40 (0.27)	4,960 (1,037)
$Alaska_{TV}$[b]				1.35 (0.22)	
FPL_{TV}[c]				1.35 (0.22)	
Wood Handbook value[d]		0.42		1.31	6,600

[a] Observed value = static bending tests conducted in the laboratory in accordance with the American Society for Testing and Materials D 198 procedures.
[b] $Alaska_{TV}$ = field (Alaska) bending modulus of elasticity results by using transverse vibration method.
[c] FPL_{TV} = laboratory (Forest Products Laboratory) bending modulus of elasticity results by using transverse vibration method.
[d] *Wood Handbook* value = based on tests of small, clear, straight-grain specimens (9).

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TABLE 11. —-Modulus of elasticity results by species, thinning regime, and Western Wood Products Association (WWPA) lumber grade.

Species and treatment	Modulus of elasticity by WWPA grade mean (standard deviation) sample size					
	Clear[a]	Select Struc.	No. 1	No. 2	Util.	Econ.
	(million psi)					
Sitka spruce						
Unthinned	1.35 (0.16) 62	1.36 (0.17) 75	1.26 (0.18) 238	1.20 (0.19) 164	1.15 (0.25) 26	1.29 (0.25) 17
Thinned	1.31 (0.15) 66	1.36 (0.16) 65	1.25 (0.20) 204	1.22 (0.17) 127	1.18 (0.16) 15	1.24 (0.20) 25
All	1.35 (0.16) 128	1.36 (0.16) 140	1.26 (0.19) 442	1.21 (0.18) 291	1.18 (0.23) 41	1.27 (0.21) 42
Western hemlock						
Unthinned	1.61 (0.21) 16	1.56 (0.19) 42	**1.37**[b] (0.19) 140	**1.28** (0.22) 193	1.29 (0.21) 18	1.43 (0.20) 9
Thinned	1.53 (0.18) 31	1.52 (0.18) 52	1.41 (0.18) 181	1.29 (0.23) 194	1.34 (0.25) 21	1.31 (0.21) 16
Fluted	1.58 (0.17) 12	1.59 (0.25) 17	**1.48** (0.24) 95	**1.44** (0.24) 113	1.40 (0.26) 22	1.41 (0.28) 7
All	1.55 (0.20) 59	1.56 (0.20) 111	1.41 (0.20) 416	1.31 (0.23) 500	1.36 (0.25) 61	1.35 (0.23) 32

[a] Clear includes C-Select and D-Select.
[b] Boldface numbers indicate a significant difference between unthinned and fluted western hemlock ($p < 0.05$).

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