The Quality of Aspen Bolts Delivered to Two Concentration Yards in Northern Minnesota

Pedro V. Sibal
James L. Bowyer

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Authors:
Pedro V. Sibal is an Instructor in the School of Forestry, University of Philippines, Los Banos. James L. Bowyer is a Professor in the Department of Forest Products, College of Forestry, University of Minnesota, St. Paul.

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Considerable volumes of aspen are used by Minnesota's pulp, paper, and waferboard industries. Lesser volumes are used in the manufacture of lumber and other solid wood products. Proposed and recently installed expansions in waferboard and paper industries have caused concern as to whether Minnesota's small, but vigorous sawmill industry will have a sufficient supply of sawlogs in the future. Two questions related to this are: (1) what is the potential for aspen sawlog production? and (2) how does this potential compare to current sawlog production?

Aspen sawlog production in the recent past was documented by the North Central Forest Experiment Station (Table 1). In 1975, approximately 13 percent of aspen harvested in Minnesota was marketed as sawlogs. It is likely that this percentage has decreased since 1975 due to increased harvest associated with waferboard production with little or no accompanying increase in sawlog sorting activity.

This paper contains information which can be used to predict the potential for aspen sawlog production (question 1). By selecting specific sawbolt characteristics (diameter, sweep, shake, and size of center defect), the sawbolt volume to be expected from a given volume of unsorted (or woodsrun) logs can be determined.

Table 1. Sawlog Production as a Percent of the Total Harvest in 1975.

Species	Total Harvest in Cords	Volume (Cord Equivalent)			Percent of Volume in Sawlogs
		Pulpwood in Cords	Sawlogs in Cords	Other in Cords	
Aspen	786,075	615,995	103,902	66,178	13.2
Paper Birch	50,225	35,474	6,079	8,672	12.1
Jack Pine	263,088	180,543	60,538	22,007	23.0
Spruce	208,556	202,004	6,552	—	3.1
Balsam Fir	125,671	121,296	4,375	—	3.5

Source: North Central Experiment Station Resource Bulletin #49.

METHODS

Log Sampling Procedure

Log size and quality was determined by inspecting randomly selected 100-inch bolts that had been delivered to two large concentration yards in Cloquet and International Falls, Minnesota. In addition, measurement of size and quality of tree-length logs was conducted at Big Falls, Minnesota. Following measurement, tree-length logs were bucked into sawlogs using a commercial slasher and the quality of a portion of the resulting sawbolts was then reevaluated. Some 1,506 tree-length logs and 6,500 bolts were measured.

In surveying 100-inch pulpwood bolts, the samples consisted of all bolts across a log pile contained within an area 3.5 to 5.5 feet above ground; this distance from the ground level was determined from one side of the pile only. If, however, more than one-half of the cross-section of a particular bolt fell outside the boundary specified above, it was excluded from the sample.

Sampling of the tree-length logs differed from that for 100-inch bolts because of difficulties in evaluating decay and measuring piled logs. Tree-length logs were taken from different sections of log piles and spread over an open area for measurement. Though sample selection was not truly random, the procedure was such that randomness was closely approximated.

Initial samples of 500 100-inch bolts were taken in both summer and winter seasons at each concentration yard. Data from these samples were then used to determine the extent to which further sampling was needed to yield representative log size class distributions. A procedure described by Freese[1] for computing the necessary sample size required to yield a given level of confidence was used in establishing the size of the additional sample needed. This method showed that approximately 6,000 observations were needed from each location for both summer and winter seasons. Since time and budget constraints did not permit this level of sampling, the coefficient of variation (CV) was fixed at a minimum acceptable level of 30 percent. No further sampling was done once this CV level was reached.

A total of 6,500 100-inch bolts were measured, distributed by location and season as follows:

Summer harvest:	2,000	bolts from Cloquet
	1,000	bolts from International Falls
Winter harvest:	1,500	bolts from Cloquet
	2,000	bolts from International Falls
Total:	6,500	bolts

[1] Freese, F. 1967. "Elementary Statistical Methods for Foresters." USDA—Forest Service, Ag. Handbook 317, 87 p.

Measuring Log Quality

The large and small end diameters of each bolt (butt, top, and diameter at breast height, respectively, of each tree length) were measured (inside bark for bolts, outside bark for tree-lengths) to the nearest one-fourth of an inch. The diameter of any defective area, the presence of ring shake, the degree of log sweep, and the length of log split were also determined.

The following criteria were used to evaluate log quality:

Sweep

Sweep was *excessive* if more than one-third of the diameter of the log would be lost in sawing a straight line parallel to the surface toward which the end curved. For tree-lengths, sweep was considered excessive if one-third or more of the diameter of each imaginary 8-foot log section (minimum of 8-inch top, diameter inside bark) would be lost in sawing a straight line parallel to the surface toward which the end curved.

Sweep was considered *moderate* if one-sixth of the diameter of the log would be lost in sawing a straight line parallel to the surface toward which the end curved.

The *no sweep* category included all logs in which less than one-sixth of the log would be lost in sawing a straight line parallel to the surface toward which the end curved.

Shake

Shake was classified as *extensive* if there were more than two growth ring separations of three-fourths of an inch or larger in length visible on both cross-sectional ends.

Shake visible on only one end of a log or shake on both ends that did not meet the criteria indicated above was classed as *moderate*.

Only logs that were totally free of shake on both ends were included in the *no shake* category.

RESULTS

100-Inch Sawbolts

Tabulations of bolt measurements are presented in Tables 2 and 3, with summaries of bolt diameter distributions and volume measurements presented in Tables 4 and 5 for Cloquet and International Falls, respectively. Tables 6 through 8 summarize bolt quality. A "t" test was used to compare bolt quality between International Falls and Cloquet. While no significant differences in sweep were noted between the two locations, shake and decay were significantly different. Bolts sampled at Cloquet had less shake and decay than those at International Falls, with both differences significant at the 0.05 level. Note (Table 8) that 25.43 percent of all bolts sampled in International Falls, and 30.17 percent of those sampled in Cloquet were completely free of defect (sweep, shake, or decay). Bolt diameter was also significantly greater in Cloquet at the 0.10 level of confidence.

Through the use of Tables 2 and 3, it is possible to assess the potential for sawbolt production from unsorted or woodsrun quantities of bolts or logs. As an example, assume that it is desired to find for the International Falls area the proportion of bolts which are 7 inches and larger in small-end diameter and which are free of sweep, shake, or decay. A listing of this data, taken from Table 2, is presented in Table 9; 18.1 percent of the total number of bolts fall into the size and quality category specified. Using average log volume figures from Table 4, the over 7-inch and defect-free logs are found to comprise 21.9 percent of the total bolt volume samples. Similar data for the Cloquet area are shown in Table 10; here, 30.3 percent of total bolt volume met the above criteria.

Tree-Length Logs

As indicated earlier, 1,506 tree-length logs were measured in the International Falls area to check bolt quality figures derived by sampling 100-inch bolts. These logs averaged 57 feet in length with a butt and top-end diameter of 11 and 4 inches, respectively. The diameter at breast height, measured 4 feet from the butt, averaged about 10 inches. Based on observations of defect at the butt end of each tree-length log, 38 percent of the total showed no decay or rot, 80 percent were totally free of ring shake, and 43 percent had no sweep (Table 11). The gross volume of the 1,506 stems was 24,354 cubic feet.

After measurement, the tree-length stems were slashed into sawlogs measuring 8 to 16 feet in length using a commercial slashing unit. Stem portions not meeting saw quality standards were chipped immediately following the slashing operation. The sawlog standard selected was basically the same as that indicated in Tables 9 and 10 (i.e., 7 inches and greater small-end diameter and free of defect).

A total of 1,131 logs were slashed from the 1,506 tree-length stems; the volume of these logs totalled 7,676 cubic feet, 31.5 percent of the original tree-length volume. Because the slasher operator had a limited view of stems during processing, and cutting standards were slightly less rigid than those indicated previously, logs were reevaluated using a more rigid criteria. Some 526 logs were randomly selected for reevaluation. Of these, 75 percent were free of sweep, 84 percent had no shake, and 78 percent had no decay (Table 11). Using a 7-inch minimum diameter, and no sweep, shake, or decay as the criteria for sawlogs, only 271 logs of the 526 in the subsample qualified. The volume of these logs totalled 1,347 cubic feet and represented 65.1 percent of the total volume of logs in the subsample (Table 12). Thus, since the preliminary findings showed that 31.5 percent of tree-length volume was of saw quality, and since 65.1 percent of the volume of those logs satisfied specific sawlog requirements upon reevaluation, the portion of tree-length volume found to meet sawlog standards was 20.5 percent (0.315 × 0.651). This is very close to the 21.9 percent sawlog figure obtained from measurement of 100-inch bolts. It also agrees closely with an estimate of 20.7 percent sawlogs by volume (7 inches in diameter and up and no defects) made after a survey of aspen bolts in five mill yards in northeast Minnesota in 1971.[1]

CONCLUSIONS

(1) There appears to be potential for increasing production of sawlogs from Minnesota aspen. Actual production of sawlogs in 1975 was 13.2 percent of the total volume harvested statewide, a figure that has likely decreased during the last seven years. In contrast, the percentage of sawbolts as a proportion of bolt volume brought to two log yards in northern Minnesota was found to be in the range of 21.9 to 30.3 percent.

(2) Both size and quality of aspen bolts were found to be better in the Cloquet location than in the area around International Falls, Minnesota. Decay and ring shake were more prevalent in aspen delivered in the International Falls area.

(3) Bolt quality as determined through measurement of 100-inch bolts yielded approximetely the same results as quality determinations involving tree-length stems.

[1] Hill, F. J., J. L. Bowyer, and J. S. Haygreen. 1971. "The Size and Quality of Woodsrun Aspen Bolts and Logs in Northeast Minnesota." Minnesota Forestry Research Notes, No. 236.

Table 2. Tabulation of Data for Aspen Bolts at International Falls.

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches)													Total in Inches		
			0	1	2	3	4	5	6	7	8	9	10	11	>11			
3	None	None	1													1	1	28
		Limited														0		
		Extensive														0		
	Moderate	None	3													3	3	
		Limited														0		
		Extensive														0		
	Excessive	None	24													24	24	
		Limited														0		
		Extensive														0		
4	None	None	21	1												22	29	185
		Limited	5					1								6		
		Extensive	1													1		
	Moderate	None	14	1												15	17	
		Limited	2													2		
		Extensive														0		
	Excessive	None	115		3		1									119	139	
		Limited	16		1											17		
		Extensive	3													3		
5	None	None	61	1	1	2										65	87	385
		Limited	13	1												14		
		Extensive	7		1											8		
	Moderate	None	55	1	1		1									58	69	
		Limited	5													5		
		Extensive	5	1												6		
	Excessive	None	178		2	2	1	1								184	229	
		Limited	31		2	1										34		
		Extensive	10		1											11		

Table 2. Tabulation of Data for Aspen Bolts at International Falls (continued).

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches)													Total in Inches		
			0	1	2	3	4	5	6	7	8	9	10	11	>11			
6	None	None	137	3	3	2	4									149	227	553
		Limited	44	1	1	4										50		
		Extensive	27		1											28		
	Moderate	None	80	1		3	5		1							90	123	
		Limited	22				2									24		
		Extensive	9													9		
	Excessive	None	137	2		4										143	203	
		Limited	40	1												41		
		Extensive	18				1									19		
7	None	None	179	3	13	14	5	1	1							216	352	578
		Limited	69	2	5	1	4	1								82		
		Extensive	48		1	3		2								54		
	Moderate	None	59		2	4	2									67	102	
		Limited	20			2										22		
		Extensive	12		1											13		
	Excessive	None	72		1	5	1									79	124	
		Limited	27		1		1	1	1							31		
		Extensive	11		1	1	1									14		
8	None	None	151	1	7	10	15	3	1	1						189	317	453
		Limited	56		2	2	8	5	1		1					75		
		Extensive	43		1	3	3	3								53		
	Moderate	None	27				3									30	58	
		Limited	14		1		1									16		
		Extensive	9			2	1									12		
	Excessive	None	47	1	1		4		1							54	78	
		Limited	12				1			1						14		
		Extensive	7			3										10		

Table 2. Tabulation of Data for Aspen Bolts at International Falls (continued).

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches)													Total in Inches		
			0	1	2	3	4	5	6	7	8	9	10	11	>11			
9	None	None	108	3		8	8	4	1	2						134	255	307
		Limited	50		1	9	4	3	2	1						70		
		Extensive	40		1	4	3	1	1			1				51		
	Moderate	None	12					1								13	25	
		Limited	5				1									6		
		Extensive	5							1						6		
	Excessive	None	7		2	1	2									12	27	
		Limited	3													3		
		Extensive	9	1		1		1								12		
10	None	None	49		5	7	6	4	3	3	4					81	166	197
		Limited	31	1			3	4	4	2						45		
		Extensive	29			3	1	5	1	1						40		
	Moderate	None	5				2		1							8	20	
		Limited	2			2		1								5		
		Extensive	4		1		1		1							7		
	Excessive	None	3			1	1									5	11	
		Limited	4						1							5		
		Extensive						1								1		
11	None	None	20		1	2	4	9	4	1	1		1			43	114	124
		Limited	21		1	1	2	3		1						29		
		Extensive	26	1		3		2	5	1	1	1	2			42		
	Moderate	None	1			1					1					3	9	
		Limited	1				1			1						3		
		Extensive				1	2									3		
	Excessive	None									1					1	1	
		Limited														0		
		Extensive														0		

Table 2. Tabulation of Data for Aspen Bolts at International Falls (continued).

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches)													Total in Inches		
			0	1	2	3	4	5	6	7	8	9	10	11	>11			
12	None	None	18			1		3	4		3	2	1			32	79	87
		Limited	12		1	2	2	2	3		1	1				24		
		Extensive	10			1	6	2		1	1	2				23		
	Moderate	None	1					1								2	6	
		Limited						1								1		
		Extensive					1			1	1					3		
	Excessive	None														0	2	
		Limited	1													1		
		Extensive					1									1		
13	None	None	10				1	4	3	1		1				20	45	47
		Limited	3					3	3	2		1				12		
		Extensive	7						1	3	1			1		13		
	Moderate	None									1					1	1	
		Limited														0		
		Extensive														0		
	Excessive	None	1													1	1	
		Limited														0		
		Extensive														0		
14	None	None	3					1		1	1		1			7	21	21
		Limited	2			1	1	1				1				6		
		Extensive	3				1		2	2						8		
	Moderate	None														0	0	
		Limited														0		
		Extensive														0		
	Excessive	None														0	0	
		Limited														0		
		Extensive														0		

Table 2. Tabulation of Data for Aspen Bolts at International Falls (continued).

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches)													Total in Inches		
			0	1	2	3	4	5	6	7	8	9	10	11	>11			
15	None	None	4					1	1		1					7	15	16
		Limited	1											1	1	3		
		Extensive	3						1		1					5		
	Moderate	None														0	0	
		Limited														0		
		Extensive														0		
	Excessive	None	1													1	1	
		Limited														0		
		Extensive														0		
16 to 20	None	None	1			1			2		1				1	6	19	19
		Limited	2			1			1							4		
		Extensive	3			1	1	2			1			1		9		
	Moderate	None														0	0	
		Limited														0		
		Extensive														0		
	Excessive	None														0	0	
		Limited														0		
		Extensive														0		
TOTAL			2468	27	67	119	120	78	52	27	22	10	5	3	2	3000	3000	3000

Table 3. Tabulation of Data for Aspen Bolts at Cloquet.

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches) 0	1	2	3	4	5	6	7	8	9	10	11	>11	Total in Inches		
3	None	None														0	0	39
		Limited														0		
		Extensive														0		
	Moderate	None														0	0	
		Limited														0		
		Extensive														0		
	Excessive	None	37													37	39	
		Limited	2													2		
		Extensive														0		
4	None	None	10													10	10	152
		Limited														0		
		Extensive														0		
	Moderate	None	11	1												12	12	
		Limited														0		
		Extensive														0		
	Excessive	None	121	2	1											124	130	
		Limited	3		1											4		
		Extensive	2													2		
5	None	None	56		1			1								58	72	410
		Limited	7		1											8		
		Extensive	3		1	2										6		
	Moderate	None	79	4	1	3										87	102	
		Limited	13													13		
		Extensive	2													2		
	Excessive	None	199	1	3	4										207	236	
		Limited	21	1												22		
		Extensive	5	1		1										7		

Table 3. Tabulation of Data for Aspen Bolts at Cloquet (continued).

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches)													Total in Inches		
			0	1	2	3	4	5	6	7	8	9	10	11	>11			
6	None	None	159	2	3	2	4	1								171	209	610
		Limited	27	3		1										31		
		Extensive	5			2										7		
	Moderate	None	136	2	7	4	1	1	1							152	182	
		Limited	16	1	2	1	1									21		
		Extensive	9													9		
	Excessive	None	162	2	3	6	2									175	219	
		Limited	30		1	2										33		
		Extensive	11													11		
7	None	None	228	4	7	14	9	2								264	342	685
		Limited	47	1	2	4	2									56		
		Extensive	16	1		3	1	1								22		
	Moderate	None	118		4	10	4									136	205	
		Limited	53	1	1	2	1									58		
		Extensive	7			2	1	1								11		
	Excessive	None	95	1	1	3			1							101	138	
		Limited	23		1	1	1									26		
		Extensive	11													11		
8	None	None	205	3	12	10	9	8	2							249	357	552
		Limited	60	1	2	4	4	2								73		
		Extensive	29			2	2	1	1							35		
	Moderate	None	75	2	1	1	2		1	1						83	116	
		Limited	19		1	1	1		1							23		
		Extensive	8				2									10		
	Excessive	None	48			2	1									51	79	
		Limited	19			1										20		
		Extensive	7							1						8		

Table 3. Tabulation of Data for Aspen Bolts at Cloquet (continued).

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches)													Total in Inches		
			0	1	2	3	4	5	6	7	8	9	10	11	>11			
9	None	None	125	4	7	11	9	5	1	1						163	266	369
		Limited	56		4	5	6	1	2							74		
		Extensive	24				3	1		1						29		
	Moderate	None	36	1	3	1	2	2								45	73	
		Limited	11	2		1	2									16		
		Extensive	12													12		
	Excessive	None	12			1				1						14	30	
		Limited	13						1							14		
		Extensive	1				1									2		
10	None	None	120	4	4	2	8	9	3	1	1	1				153	249	293
		Limited	43	1	1	6	5	1	4							61		
		Extensive	20	1	4	1	3	4		1	1					35		
	Moderate	None	17			1	1		1		1					21	36	
		Limited	7						2							9		
		Extensive	4					2								6		
	Excessive	None	6													6	8	
		Limited	1													1		
		Extensive	1													1		
11	None	None	71		2	3	9	2	3	3	1					94	157	171
		Limited	27		3		4	3	3		1					41		
		Extensive	14				1	4	1	1	1					22		
	Moderate	None	3				1									4	12	
		Limited	5													5		
		Extensive	3													3		
	Excessive	None	1													1	2	
		Limited														0		
		Extensive	1													1		

Table 3. Tabulation of Data for Aspen Bolts at Cloquet (continued).

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches) 0	1	2	3	4	5	6	7	8	9	10	11	>11	Total in Inches		
12	None	None	41		1	1	2	1	3	2	1					52	94	95
		Limited	13		1	2	2		3	2		1				24		
		Extensive	12		1				3		1		1			18		
	Moderate	None														0	0	
		Limited														0		
		Extensive														0		
	Excessive	None														0	1	
		Limited														0		
		Extensive	1													1		
13	None	None	19			2	3	2	3	1						30	52	57
		Limited	4			1	1	2		1	2					11		
		Extensive	5		1	2	2				1					11		
	Moderate	None	2						1		1					4	5	
		Limited										1				1		
		Extensive														0		
	Excessive	None														0	0	
		Limited														0		
		Extensive														0		
14	None	None	13			1	1		1	1						17	30	31
		Limited	2			1		1	1							5		
		Extensive	2				1	2	2		1					8		
	Moderate	None												1		1	1	
		Limited														0		
		Extensive														0		
	Excessive	None														0	0	
		Limited														0		
		Extensive														0		

Table 3. Tabulation of Data for Aspen Bolts at Cloquet (continued).

Log Diameter (Small End Inches)	Sweep	Shake	Decay (Diameter of Decayed Area in Inches)													Total in Inches		
			0	1	2	3	4	5	6	7	8	9	10	11	>11			
15	None	None	6						1	1	1		1			10	15	16
		Limited	1						1							2		
		Extensive	2										1			3		
	Moderate	None														0	1	
		Limited							1							1		
		Extensive														0		
	Excessive	None														0	0	
		Limited														0		
		Extensive														0		
16 to 22	None	None	3	1					1	1	2				3	11	20	20
		Limited	4						1				1			6		
		Extensive	1				1		1							3		
	Moderate	None														0	0	
		Limited														0		
		Extensive														0		
	Excessive	None														0	0	
		Limited														0		
		Extensive														0		
TOTAL			2959	48	89	130	116	60	51	20	16	3	4	1	3	3500	3500	3500

Table 4. Cubic Foot Volume[a] of 100-Inch Aspen Bolts at International Falls.

Log Diameter (Inside Bark at Small End) in Inches	Number of Bolts	Gross Cubic Foot Volume of Xylem			Percent of Total Number of Bolts in Diameter Class	Percent of Total Bolt Volume in Diameter Class	Cumulative Bolt Volume
		Minimum	Average	Maximum			
3	28	0.43	0.67	1.15	0.93	0.20	0.20
4	185	0.62	0.97	1.67	6.16	1.93	2.13
5	385	0.98	1.37	2.06	12.83	5.67	7.80
6	553	1.32	1.87	3.56	18.43	11.10	18.90
7	578	1.84	2.49	3.79	19.27	15.45	34.35
8	453	2.45	3.19	4.98	15.10	15.51	49.86
9	307	3.15	4.03	5.95	10.23	13.28	63.14
10	197	4.04	4.99	7.99	6.57	10.55	73.69
11	124	4.81	5.99	8.83	4.13	7.97	81.66
12	87	6.02	7.14	11.02	2.90	6.67	88.33
13	47	7.10	8.71	13.31	1.57	4.39	92.72
14	21	8.10	9.74	12.88	0.70	2.19	94.91
15	16	9.83	11.33	14.53	0.53	1.95	96.86
16	10	11.89	14.75	17.13	0.33	1.58	98.44
17	5	12.99	15.51	18.87	0.17	0.83	99.27
18	3	15.36	15.16	15.79	0.10	0.49	99.76
19	0	—	—	—	—	0.00	99.76
20	1	—	23.26	—	0.03	0.25	100.01
	3,000				99.98		

[a]Volume calculated using Smalian's formula and actual measurements at each end (to nearest 0.25 inches).

Table 5. Cubic Foot Volume[a] of 100-Inch Aspen Bolts at Cloquet.

Log Diameter (Inside Bark at Small End) in Inches	Number of Bolts	Gross Cubic Foot Volume of Xylem			Percent of Total Number of Bolts in Diameter Class	Percent of Total Bolt Volume in Diameter Class	Cumulative Bolt Volume
		Minimum	Average	Maximum			
3	39	0.43	0.64	0.89	1.11	0.22	0.22
4	152	0.62	0.94	1.51	4.34	1.27	1.49
5	410	0.93	1.35	2.37	11.71	4.91	6.40
6	610	1.32	1.84	3.93	17.43	9.96	16.36
7	685	1.77	2.46	3.87	19.57	14.94	31.30
8	552	2.45	3.16	4.54	15.77	15.47	46.77
9	369	3.25	4.06	5.66	10.54	13.29	60.06
10	293	3.94	4.97	7.20	8.37	12.92	72.98
11	171	4.61	6.10	10.76	4.89	9.25	82.23
12	95	5.77	7.24	12.14	2.71	6.10	88.33
13	57	6.82	8.45	11.85	1.63	4.27	92.60
14	31	8.25	10.08	14.36	0.89	2.77	95.37
15	16	9.82	11.62	15.47	0.46	1.65	97.02
16	7	11.17	13.56	18.15	0.20	0.84	97.86
17	5	12.99	15.59	19.94	0.14	0.69	98.55
18	4	15.79	19.18	26.05	0.11	0.68	99.23
19	1	—	15.34	—	0.03	0.14	99.37
20	2	18.35	22.94	27.52	0.06	0.41	99.78
21	0	—	—	—	—	0.00	99.78
22	1	—	25.99	—	0.03	0.23	100.01
	3,500				99.99		

[a]Volume calculated using Smalian's formula and actual measurements at each end (to nearest 0.25 inches).

Table 6. Summary of Shake and Sweep Defects.

Shake / Sweep	No Shake		Limited Shake		Extensive Shake		Row Total	
	I. Falls	Cloquet	I. Falls	Cloquet	I. Falls	Cloquet	I. Falls	Cloquet
No Sweep	972[a]	1282	420	392	335	199	1727	1873
	56.28[b]	68.45	24.32	20.93	19.40	10.62	100.00	100.00
	51.56[c]	50.41	64.62	59.30	72.04	67.23	—	—
	32.40[d]	36.63	14.00	11.20	11.17	5.69	57.57	53.52
Moderate	290	545	84	147	58	53	432	745
	67.13	73.15	19.44	19.73	13.43	7.11	100.00	99.99
	15.38	21.43	12.92	22.23	12.47	17.91	—	—
	9.67	15.57	2.80	4.20	1.93	1.51	14.40	21.28
Excessive	623	716	146	122	72	44	841	882
	74.08	81.18	17.36	13.83	8.56	4.99	100.00	100.00
	33.05	28.16	22.46	18.46	15.48	14.86	—	—
	20.77	20.46	4.87	3.49	2.40	1.26	28.03	25.21
Column Total	1885	2543	650	661	465	296	3000	3500
	—	—	—	—	—	—	—	—
	99.99	100.00	100.00	99.99	99.99	100.00	—	—
	62.83	72.66	21.67	18.89	15.50	8.46	100.00	100.01

[a]Number of bolts
[b]Row percentage
[c]Column percentage
[d]Total percentage

Table 7. Cross Tabulation of Sweep and Shake Controlling for No Decay.

Shake / Sweep	No Shake		Limited Shake		Extensive Shake		Row Total	
	I. Falls	Cloquet	I. Falls	Cloquet	I. Falls	Cloquet	I. Falls	Cloquet
No Sweep	763[a]	1056	309	291	247	133	1319	1480
	30.92[b]	35.69	12.52	9.83	10.01	4.49	53.44	50.01
	25.43[c]	30.17	10.30	8.31	8.23	3.80	43.96	42.28
Moderate Sweep	257	477	71	124	44	45	372	646
	10.41	16.12	2.88	4.19	1.78	1.52	15.07	21.83
	8.57	13.63	2.37	3.54	1.47	1.29	12.41	18.46
Excessive Sweep	585	681	134	112	58	40	777	833
	23.70	23.01	5.43	3.79	2.35	1.35	31.48	28.15
	19.50	19.46	4.47	3.20	1.93	1.14	25.90	23.80
Column Total	1605	2214	514	527	349	218	2468	2959
	65.03	74.82	20.83	17.81	14.14	7.36	100.00	99.99
	53.50	63.26	17.14	15.05	11.63	6.23	82.27	84.54

[a]Number of bolts
[b]Percentage of total number of bolts without decay (2468 I. Falls, 2959 Cloquet)
[c]Percentage of total number of bolts sampled (3000 at I. Falls, 3500 at Cloquet)

Table 8. Summary of Bolt Size and Defects.[a]

	International Falls	Cloquet	Average
Size			
Small End Diameter (inches)	7.565	7.630	7.600
Large End Diameter (inches)	8.600	8.749	8.680
Defect Category			
No Sweep	1727[b]	1873	55.38
	57.57[c]	53.51	
No Shake	1885	2543	68.12
	62.83	72.65	
No Decay	2468	2959	83.49
	82.27	84.54	
No Sweep and No Decay	972	1282	34.68
	32.40	36.63	
No Sweep, No Shake,	763	1056	27.98
No Decay	25.43	30.17	

[a]All bolts 100-inches in length
[b]Number of bolts
[c]Percent of total number of bolts sampled (3000 at I. Falls, 3500 at Cloquet)

Table 9. Potential Sawbolt Volume[a] from 100-Inch Aspen Bolts at International Falls.[b]

				Bolts of Saw Quality			
(1) Diameter (Inside Bark at Small End) in Inches	(2) Number of Bolts	Volume in Cubic Feet (3) Gross	(4) Mean	(5) Number	(6) Volume in Cubic Feet	(7) Percent of Total Volume	(8) Cumulative Percent Distribution
3	28	18.76	0.67				
4	185	179.45	0.97				
5	385	527.45	1.37				
6	553	1034.11	1.87				
7	578	1439.22	2.49	179	445.71	.048	.048
8	453	1445.07	3.19	151	481.69	.052	.100
9	307	1237.21	4.03	108	435.24	.047	.147
10	197	983.03	4.99	49	244.51	.026	.173
11	124	742.76	5.99	20	119.80	.013	.186
12	87	621.18	7.14	18	128.52	.014	.200
13	47	409.37	8.71	10	87.10	.009	.209
14	21	204.54	9.74	3	29.22	.003	.212
15	16	181.28	11.33	4	45.32	.005	.217
16	10	147.50	14.75	—	—	—	.217
17	5	77.55	15.51	1	15.51	.002	.219
18	3	45.48	15.16				
19	0	—	—				
20	1	23.26	23.26				
Total	3000	9317.22		543 (18.1% of 3000)	2032.62		

[a]Sawbolts defined as bolts 7 inches or greater in diameter (small end, inside bark) without sweep, shake, or decay.
[b]Columns 1 through 4 taken from Table 4. Column 5 derived from Table 2. Columns 6 through 8 obtained by combining information from columns 4 and 5.

Table 10. Potential Sawbolt Volume[a] from 100-Inch Aspen Bolts at Cloquet.[b]

(1) Diameter (Inside Bark at Small End) in Inches	(2) Number of Bolts	Volume in Cubic Feet (3) Gross	(4) Mean	Bolts of Saw Quality (5) Number	(6) Volume in Cubic Feet	(7) Percent of Total Volume	(8) Cumulative Percent Distribution
3	39	24.96	0.64				
4	152	142.88	0.94				
5	410	553.50	1.35				
6	610	1122.40	1.84				
7	685	1685.10	2.46	228	560.88	.052	.052
8	552	1352.40	2.45	205	502.25	.046	.098
9	369	1498.14	4.06	125	507.50	.047	.145
10	293	1456.21	4.97	120	596.40	.055	.200
11	171	1043.10	6.10	71	433.10	.040	.240
12	95	687.80	7.24	41	296.84	.027	.267
13	57	481.65	8.45	19	160.55	.015	.282
14	31	312.48	10.08	13	131.04	.012	.294
15	16	185.92	11.62	6	69.72	.006	.300
16	7	94.92	13.56	2	27.12	.002	.302
17	5	77.95	15.59	1	15.59	.001	.303
18	4	76.72	19.18				
19	1	15.34	15.34				
20	2	45.88	22.94				
21	0	—	—				
22	1	25.99	25.99				
Total	3500	10,883.34		831 (23.7% of 3500)	3300.99		

[a]Sawbolts defined as bolts 7 inches or greater in diameter (small end, inside bark) without sweep, shake, or decay.
[b]Columns 1 through 4 taken from Table 5. Column 5 derived from Table 3. Columns 6 through 8 obtained by combining information from columns 4 and 5.

Table 11. Tree-Length Stem Data: Summary of Defects.

Criteria/Item	Tree-length[a] Number of Cases	Tree-length[a] Percent of Total Number of Stems	Sawlogs[b] Number of Cases	Sawlogs[b] Percent of Total Number of Logs in Sub-Sample
Sweep				
No Sweep	650	43.2	396	75.3
Moderate	423	28.1	108	20.5
Excessive	433	28.8	22	4.2
Shake				
No Shake	1210	80.3	441	83.8
Limited	223	14.8	82	15.6
Extensive	73	4.8	3	0.6
Decay				
No Decay	592	39.3	410	77.9
Total Number of Samples	1506		526	

[a]Tree-length woodsrun aspen logs. Shake and decay evaluated at butt ends of logs.
[b]Sub-sample of the 1,131 logs obtained from tree-length stems.

Table 12. Tree-Length Stem Data: Reevaluation of Logs Slashed from Tree-Length Logs.

Log Diameter (Inside Bark at Small End) in Inches	Sample of Logs Slashed from Tree-Length Stems			Logs of Saw Quality[a]			
	Number of Cases	Volume in Cubic Feet		Number of Cases	Volume in Cubic Feet	Percent of Total Volume	Cumulative Percent Distribution
		Gross	Mean				
7	25	70.660	2.826	14	39.564	1.91	1.91
8	146	495.810	3.396	84	285.264	13.78	15.69
9	138	753.000	4.055	72	392.904	18.94	34.63
10	100	504.960	5.050	51	257.550	12.44	47.07
11	62	385.020	6.210	26	161.460	7.80	54.87
12	28	213.920	7.640	12	91.680	4.43	59.30
13	16	140.860	8.804	7	61.628	2.98	62.28
14	7	73.910	10.559	3	31.677	1.53	63.81
15	3	37.140	12.380	1	12.380	0.60	64.61
16	1	12.480	12.480	1	12.480	0.60	65.01
Total	526	2069.76		271[b]	1346.59[c]		

[a] 7 inches minimum small-end diameter with no sweep, shake, or decay.
[b] Percent sawlogs (as % of number of logs) $^{271}/_{526} \times 100 = 51.52\%$
[c] Percent sawlogs (as % of total volume of logs) $^{1346.59}/_{2069.76} \times 100 = 65.06\%$