

Effects of Bear Damage on Douglas-Fir Lumber Recovery

• **Eini C. Lowell, Dennis Dykstra, and George McFadden**

ABSTRACT

Bear actively resulting in injury to Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) trees has been documented as early as the mid-1850s in the Pacific Northwest. The study reported in this article was designed to help managers decide whether the common practice of removing the damaged but potentially valuable butt section of the bottom log and leaving it in the woods is warranted. Thirty-four damaged and 28 undamaged trees were selected from three sites in western Washington where bear damage has been a persistent problem. Trees were felled and bucked into 16-ft lengths. The damaged trees in the sample had been injured at ages between 10 and 15 years at two sites and between 10 and 65 years at the third site. The primary scaling deductions were for ring and scar defects. The 16-ft butt logs from the damaged and undamaged trees were sawn into dimension lumber. Bear-damaged logs were found to have lower cubic volume recovery than undamaged logs having the same small-end diameters. Lumber grade recovery was also influenced by bear damage; logs from damaged trees had a lower percentage of high-value lumber. The analysis suggests that the optimal harvesting policy is to haul the entire butt log to the mill rather than leaving the damaged portion in the woods. Although the value of the damaged portion is lower, most of the lumber recovered from that section can be used, with only a modest reduction in grade and value.

Keywords: bear damage, Douglas-fir lumber recovery, log value

Bear damage to trees in Oregon was documented as early as the mid-1850s (Kanaskie et al. 1990). In some localities, it is reportedly common for black bears (*Ursus americanus*) emerging from winter denning to feed on trees by stripping away the bark near the base of the tree with their claws and teeth and using their incisors to expose and eat the new sapwood (Radwan 1969, Poelker and Hartwell 1973). This occurs in the spring, when the sap is running, through early summer, when the bark is easy to peel and the sapwood high in sugars. As the season progresses, bears move into higher elevation stands in response to tree phenological development (Schmidt and Gourley 1992). The level of this type of activity declines as fruits and berries ripen (Flowers 1987). A single bear can reportedly feed on as many as 70 trees per day (Schmidt and Gourley 1992).

Trees in stands where forest management activities such as thinning and fertilization have been implemented to increase productivity are favored by bears (Kanaskie et al. 1990, Ziegler 1994, and Nolte 2001). Nolte et al. (2003) found that trees in thinned stands have higher sugar content in the sapwood than trees in unthinned stands. Bears also have species preferences based on geographic location. In western Oregon and Washington, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) is the preferred species (Stewart et al. 1999), whereas in northwestern Montana, western larch (*Larix occidentalis* Nutt.) is the species of choice (Mason and Adams 1989).

Several research studies have found that bears prefer young, smooth-barked trees that are easy to peel (Levin 1954, Hartwell 1973, Schmidt and Gourley 1992, Nolte et al. 2003). Trees dam-

aged by bears range in age from 10 to 40 years and in dbh from 5 to 18 in. at the time of damage (Schreuder 1976). The selection of trees by bears in a specific stand appears to follow no predictable pattern but is randomly distributed throughout the stand (Schmidt and Gourley 1992). Some stands are damaged repeatedly (Hartwell and Johnson 1988). Schmidt and Gourley (1992) attributed this to learned behavior passed from sows to cubs. Bears generally feed on the lower part (1-5 ft) of the tree bole, either girdling and killing the tree or partially peeling the bole. A survey done by Kanaskie et al. (2001) found a ratio of 2:1 for partially peeled trees to completely girdled trees. Occasionally, the bears will climb larger trees and feed on upper boles (Schmidt and Gourley 1992). Vulnerable stands may have 5-10% of the trees damaged each year (Ziegler 1994).

Damage to trees by bears may result in any of several stand responses. Miller et al. (2007) found that in some circumstances, partially girdled trees can grow faster in diameter than undamaged trees, with no change in form. In contrast, Nelson (1989) recorded a reduction in growth rates when trees were partially girdled by bears. Miller et al. (2007) also noted that if a stand is managed on a short rotation, the trees have little time to recover from partial girdling, and the damage can represent a greater portion of stem volume. In addition, the damage caused by bears stripping the bark can include introduction of stain and decay fungi and scarring, thus increasing stem defect volume and reducing product volume and value when the trees are harvested.

Occurrence of bear damage is reported to have increased noticeably in western Washington in the 1940s, and by the early 1970s it

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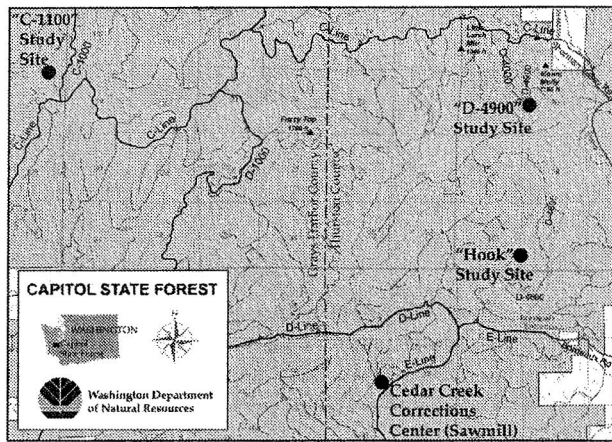


Figure 1. Locations of the three sites (C-1100, D-4900, and Hook) from which sample trees were extracted on the Capitol State Forest near Olympia, WA. Also shown is the location of the Cedar Creek Corrections Center, where the logs were sawn into lumber.

was found in all areas of the Capitol State Forest managed by the Washington State Department of Natural Resources (Hartwell 1973). The high level of incidence of bear damage throughout this important timber-producing forest led managers to seek information on the value and volume losses associated with lumber produced from damaged trees.

Most research on bear damage to trees has dealt with species preferences, geographic location of damage, and tree mortality rates. The economic effect of this activity has received less attention. Pierson (1966) presented data from a Forest Service study suggesting that merchantable volume loss was 10% if half of a tree's circumference was peeled and 7% if less than half of the circumference was peeled. No published work has previously examined the quantity and quality of wood products manufactured from harvested bear-damaged trees. Common practice when harvesting a bear-damaged tree is to remove the butt section of the bottom log and leave it in the woods. This practice, called "long butting," often results in 8 ft or more of the high-quality butt log being discarded. The study reported here was designed to determine relationships among scaled defect, lumber volume recovery, and lumber quality (based on lumber grade) to help managers decide whether the practice of leaving a valuable section of the tree bole in the woods is warranted. We did not, however, attempt to consider all possible markets, such as those for export logs or utility poles. Instead, our analysis is limited to the production of dimension lumber from both damaged and undamaged logs.

Materials and Methods

Three sites that had experienced bear damage were chosen on the Capitol State Forest managed by the Washington Department of Natural Resources near Olympia, WA (Figure 1). At each site, a sample of 10 trees with closed wounds that are external indicators of damage was selected (Figure 2). A corresponding sample of 10 undamaged trees, which exhibited no external signs of bear damage, was also identified. Damaged and undamaged trees were paired within each of the three sites based on tree dbh. Wound closure on bear-damaged trees can be such that the external indicators disappear after some years, making it difficult for field personnel to determine whether a particular tree has been damaged. Because the



Figure 2. Example of the type of external indicator used to select trees suspected of having suffered bear damage. A 6-in. ruler has been placed in the image for scale, just above the defect indicator. (Photo courtesy of Washington Department of Natural Resources.)

frequency of damaged trees was exceptionally high at the Hook site, two extra trees thought to be undamaged were added to the sample at that site in case some of the trees without visible indicators were later found to be damaged.

At each of the sites, both damaged and undamaged sample trees were felled and bucked to merchantable lengths. Since bear damage is generally limited to the lower bole, only the first 32 ft of the bole were evaluated for inclusion in the study. Should no damage be evident in the second (upper) 16-ft log when bucked, then only the first 16 ft of the bole would be processed for the study. Tree age at the time of harvest and the age when damage occurred were determined by ring count on the stump.

Logs were hauled to the Cedar Creek Corrections Center at Littlerock, WA, for scaling and processing. The center operates a small sawmill for training of inmates. Scaling was done by a Forest Service measurement specialist according to Forest Service scaling rules for Scribner (US Forest Service 1985) and cubic (US Forest Service 1991) volumes. Logs were sawn using a TimberPro mill with a saw kerf of 1/8 in. The sawmill had no optimizing equipment. Because of needs at the Corrections Center, dimension lumber was the primary product manufactured. One-inch boards were also produced from slabs. Logs were turned as needed to achieve the highest possible lumber grades. The sawing pattern was diagrammed for

Table 1. Summary of data used in the statistical analysis of cubic lumber recovery, with mean values shown both for the three study sites individually and for all sites combined.

Attribute	Mean, C-1100	Mean, D-4900	Mean, Hook	Mean, all sites	Range, all sites
Bear-damaged trees	<i>n</i> = 12	<i>n</i> = 11	<i>n</i> = 11	<i>n</i> = 34	<i>n</i> = 34
Diameter at breast height (in.)	22.4	16.5	15.0	18.1	13.5–30.7
Tree height (ft)	134.7	80.1	87.0	101.6	63.6–168
Stump age (years)	72.6	30.3	30.6	45.3	28–82
Age when damage occurred (years)	25.9	14.6	11.2	17.5	5–64
Small-end diameter of butt log (in.)	17.5	13.4	12.5	14.5	11.2–25.3
Gross volume of 16-ft butt log (bd ft)	216	107	89	140	70–460
Gross volume of 16-ft butt log (ft ³)	33.6	20.5	17.5	24.2	13.4–59.1
Net ft ³ lumber recovery as a percentage of ft ³ gross log volume (%)	51.9	44.6	43.4	46.8	32.3–64.2
Undamaged trees	<i>n</i> = 8	<i>n</i> = 9	<i>n</i> = 11	<i>n</i> = 28	<i>n</i> = 28
Diameter at breast height (in.)	23.2	16.2	15.4	17.9	13.7–30.8
Tree height (ft)	143.8	78.4	88.0	100.8	70.6–158
Stump age (years)	79.8	29.4	31.8	44.8	26–85
Age when damage occurred (years) (not applicable)					
Small-end diameter of butt log (in.)	18.8	13.6	12.7	14.7	11.1–23.9
Gross volume of 16-ft butt log (bd ft)	249	108	91	141	70–460
Gross volume of 16-ft butt log (ft ³)	36.4	19.4	17.4	23.5	12.7–55.9
Net ft ³ lumber recovery as a percentage of ft ³ gross log volume (%)	55.0	53.5	50.6	52.8	36.4–64.7
All trees	<i>n</i> = 20	<i>n</i> = 20	<i>n</i> = 22	<i>n</i> = 62	<i>n</i> = 62
Diameter at breast height (in.)	22.7	16.3	15.2	18.0	13.5–30.8
Tree height (ft)	138.3	79.3	87.5	101.2	63.6–168
Stump age (years)	75.5	29.9	31.2	45.1	26–85
Age when damage occurred (years) (damaged trees only)					
Small-end diameter of butt log (in.)	18.0	13.4	12.6	14.6	11.1–25.3
Gross volume of 16-ft butt log (bd ft)	229	108	90	140	70–460
Gross volume of 16-ft butt log (ft ³)	34.7	20.0	17.4	23.8	12.7–59.1
Net ft ³ lumber recovery as a percentage of ft ³ gross log volume (%)	53.1	48.6	47.0	49.5	32.3–64.7

each log, and a diagram was also made showing the extent and types of defect in each individual board.

Lumber was dried and surfaced to standard dressed dry dimensions. Lumber grade, length, and width were tallied and the grade-controlling defect was recorded for each piece of lumber. A Western Wood Products Association (WWPA) certified lumber inspector graded the 2 X 4 dimension lumber under the WWPA Structural Light Framing rules and the 2 X 6 and wider dimension lumber under the WWPA Structural Joists and Planks rules (WWPA 2005). One-inch boards were graded under WWPA's Selects and Commons rules.

Statistical Analysis System software version 9.1 (SAS Institute Inc. 2004) was used to analyze data on lumber volume and value recovery. Regression models were developed using a logarithmic transformation of log small-end diameter as the independent variable. The dependent variable for volume was cubic lumber volume as a percentage of gross cubic log volume. Value was based on lumber grade and year-end price from WWPA (2007). Dollars per thousand board feet lumber tally (DMLT), the average value of lumber produced from an individual log, was calculated for each log. This measure of value was used as the dependent variable as it contains no bias associated with defect estimation but measures the inherent quality of the log. The best-fitting model for each regression equation was selected by examining the Student's *t* statistic for each regression coefficient individually and the coefficient of determination (R^2) and the *F* statistic for each equation as a whole. Analysis of covariance was used to determine whether individual regression equations derived independently for damaged and for undamaged trees differed significantly.

Results and Discussion

Classification of trees at the time of selection as either damaged or undamaged was based on external indicators. During the selection process, 30 sample trees were classified as damaged, and 32 were classified as undamaged. After being felled, four trees without external indicators were found to exhibit internal defects of the type caused by bears and were therefore reclassified as damaged trees. Thus, the final sample included 28 undamaged trees and 34 damaged trees. All three sites had trees that were originally classified as undamaged but were reclassified as damaged after being felled.

Damage occurred between 10 and 15 years at two of the sites (D-4900 and Hook) and between 10 and 64 years at C-1100 (Table 1). The average stump age of trees at the C-1100 site (about 75 years) was much greater than at the other two sites (about 30 years). At the C-1100 site, damage to one tree occurred at age 42 and to another at age 64. Both these trees were at the upper half of the dbh range for that site. Although bear damage is not typical at this stage of tree development because Douglas-fir bark is generally too thick at that age to attract bears when the sap is running, at least one report suggests that bears may occasionally damage trees older than 45 years (Schreuder 1976). We therefore decided to retain these two trees in the sample of bear-damaged trees.

As the damaged sample trees were being felled, we examined each to determine how far up the bole the stain or other injury associated with the damage extended. None of the damaged trees exhibited any such defects above the first 16 ft of the lowest 32-ft woods-length log. Woods-length logs bucked into 16-ft lengths for sawmill use exhibited defects related to bear damage only in the 16-ft butt log, and in most cases the extent of injury was limited to the first few feet of that log. Since the objective of the study was to compare lumber

Table 2. Cubic and Scribner scaled volumes for the 16-ft sample logs. Thirty-four of the sample logs were classified as damaged and 28 as undamaged.

	Cubic volume			Scribner volume		
	Gross	Net	Sound (%)	Gross	Net	Sound (%)
	 (ft ³)			 (board feet)		
Damaged	720	676	93	4140	3610	85
Undamaged	758	736	98	4570	4500	99

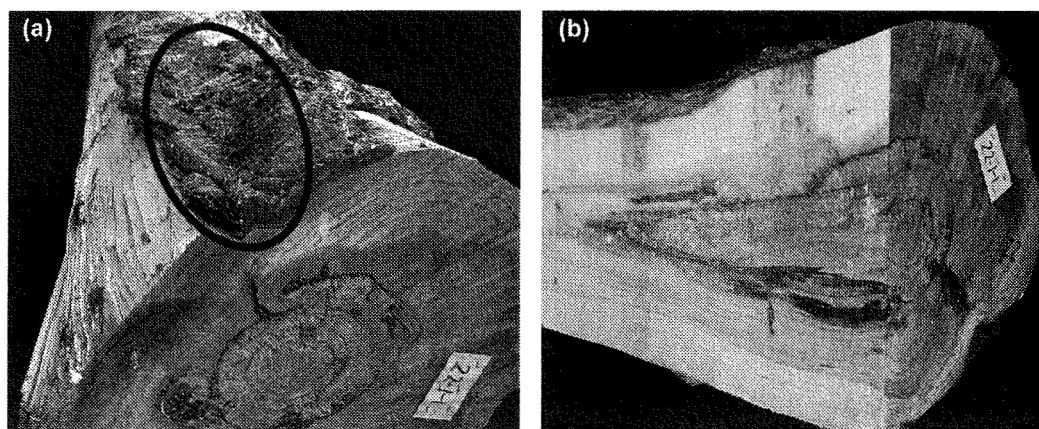


Figure 3. Two views of a bear-damaged log. The image background has been removed for clarity. (a) Left image: The butt end of the log showing both ring and scar (catface) defects. The catface scar is outlined with an oval. The triangular slab removed from the log along the left side split off during felling and is not a bear-related defect. (b) Right image: The same log after it was partially opened at the sawmill. Staining associated with the bear damage extended about 4 ft up the log from the butt end. This particular log also had rot and pitch defects that extended less than 2 ft from the butt. (Photos by Eini C. Lowell.)

from bear-damaged logs with that from undamaged logs, and because bear damage did not extend above the lowest few feet of the bole, we included only the 16-ft mill log taken from the butt of the tree in our sample to be scaled for defects and processed into lumber. None of these butt logs had such extensive defect that a sawmill would reject it for lumber production.

We recognize that sawmills may require logs in lengths other than the 16 ft included in this study. Foresters often assume that west-side mills prefer 32-ft logs. In recent years, however, this standard has changed considerably, with west-side log buyers now specifying a variety of lengths between 16 and 42 ft or more, depending on mill capabilities and market conditions.

Log Scale Volume

Scaled volumes (both cubic and Scribner) are shown in Table 2. The primary defects warranting deductions were ring (occasionally with rot inside) and scar (catface) defects (Figure 3). Scribner scaling resulted in a much lower percentage of sound wood than cubic scaling (85 versus 93%, respectively) because Scribner is based on the small-end diameter of the log and much of the defect fell within that scaling cylinder. In the undamaged logs, sweep was the most common defect.

Damage seldom extended very far up the bole (Figure 3b) and generally had little effect outside the annual ring where the bear damage took place. Fourteen bear-damaged trees had deductions for ring that averaged 2.9 ft in length. Catface deductions were assessed in logs from 18 bear-damaged trees, with an average defect length of 4 ft.

Cubic Lumber Recovery

Theoretically, recovery of cubic *lumber* volume as a percentage of cubic *log* volume should increase as the diameter of logs being sawn increases, but the rate of increase should decline as the diameter gets larger. This type of trend is often well-described by a logarithmic transformation on the independent variable (log small-end diameter in this case). We used linear regression procedures to test statistical relationships between log diameter and lumber recovery for both the untransformed diameter and the logarithmic transformation. Equations fit against the untransformed diameter were generally poor, with weak statistical relationships for the overall equation and for individual parameters. Those regressed against the natural logarithm of the diameter fit the data much better and were highly significant.

We calculate net cubic volume recovery as

$$R = V_{\text{Lbr}}/V_{\text{Log}}, \quad (1)$$

where R = ft³ of net lumber volume recovered per gross ft³ of volume in the butt log, expressed as a fraction between 0 and 1; V_{Lbr} = ft³ of net lumber volume produced from the butt log, calculated from the dimensions of the lumber pieces after surfacing and after subtracting any length trim attributed to bear damage; and V_{Log} = ft³ of gross volume in the butt log (gross rather than net log volume is used to avoid potential inconsistencies associated with local scaling practices).

Data used in the statistical analysis of net cubic volume recovery are summarized in Table 1. Although mean values are shown in the table for each of the three sites, data from all sites combined were

used in the statistical analysis. Note that the number of observations differs between damaged and undamaged trees.

Most of the data ranges summarized in Table 1 represent non-normal distributions and are skewed toward smaller values. For most damaged trees, the damage occurred at a young age regardless of the age at the time of felling. There were two outliers from the C-1100 site: damage to one tree occurred at age 42 and another at age 64. Although these trees may have been damaged by another agent, such as tree fall, instead of bears, the characteristics of the injuries were consistent with bear damage, and we therefore included these two trees in the analysis as damaged trees.

From a series of linear and nonlinear models tested with regression analysis, the model that provided the best overall fit to the data was

$$\hat{R} = \beta_0 + \beta_1 \cdot \log_e(D_s) + \beta_2 \cdot \delta, \quad (2)$$

where R = estimated cubic recovery in ft³ of net lumber volume recovered per gross ft³ of volume in the butt log, expressed as a fraction between 0 and 1; D_s = inside-bark diameter of the butt log at the small end, in inches, averaged from two measurements taken at right angles and measured to the nearest 0.1 in.; $\log_e(\cdot)$ = the inverse of the exponential function, the logarithm to the base e , where e = the irrational constant 2.71828182846 ...; δ = a classification variable with a value of 1 if the tree was classified as damaged and a value of 0 otherwise; β_0 = the regression parameter for the intercept term; β_1 = the regression parameter for the independent variable $\log_e(D_s)$, the natural logarithm of the small-end diameter of the 16-ft butt log; and β_2 = the regression parameter for the classification variable 0.

The model of Equation 2 includes both damaged and undamaged trees in a single equation and can thus be used directly to find the difference in the estimated cubic recovery fraction between damaged and undamaged trees. This difference is equal to the value of the regression coefficient β_2 . However, fitting the data to the model of Equation 2 assumes that the rate at which cubic recovery changes relative to log diameter is the same for both damaged and undamaged trees. Stated differently, Equation 2 assumes that the regression slope coefficient β_1 does not differ significantly for damaged and undamaged trees. To determine whether this is a reasonable assumption, the following alternative formulation was tested:

$$\hat{R}_j = \beta_{0,j} + \beta_{1,j} \cdot \log_e(D_{s,j}), \quad (3)$$

where the subscript $j = 1, 2$ was used to identify subsamples of the data representing damaged and undamaged trees, respectively. The alternative model described by Equation 3 permits the effect of log diameter on cubic volume recovery to differ between damaged and undamaged trees. However, analysis of covariance with the data from this study suggested that the regression slope coefficients $\beta_{1,1}$ and $\beta_{1,2}$ estimated independently for damaged and undamaged trees using Equation 3 were not statistically different at the 90% confidence level. This validates the assumption of the model in Equation 2, which was therefore selected for use in the analysis.

Results of the statistical analysis from fitting Equation 2 to the data from this study suggest that cubic volume recovery in the butt log is positively correlated with the small-end diameter of the log and that the butt logs of bear-damaged trees can be expected to have lower cubic volume recovery percentages as compared with butt logs of undamaged trees having the same small-end diameters (Figure 4; Table 3). This reduction is constant over all diameters within the

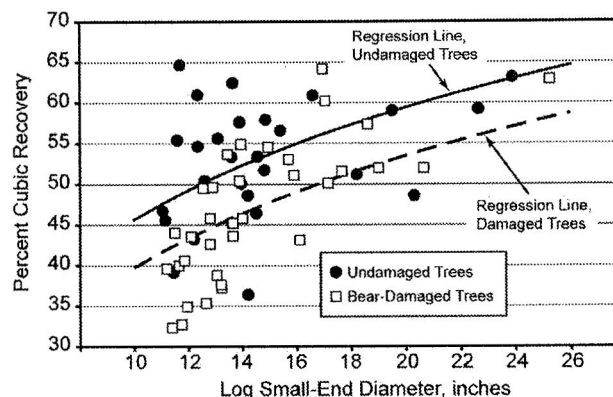


Figure 4. Relationship between log small-end diameter and cubic volume recovery when the rate of change in recovery with respect to a change in log diameter is assumed to be the same for damaged and undamaged trees. The regression lines were fitted to Equation 2, with statistical results as summarized in Table 4.

range of the sample trees in the study, as can be seen from the fact that the two regression lines in Figure 4 follow parallel curves. The estimated reduction in cubic volume recovery from the butt log of a damaged tree compared with that from an undamaged tree can be obtained from the coefficient fitted to parameter β_2 (Table 3). Expressed as a recovery percentage, the difference is about 6% for all log diameters.

Estimating Volume Loss with dbh

Because personnel assessing the value of timber in a stand in preparation for harvest typically have data available to them on dbh rather than on the small-end diameter of the first 16-ft butt log in each tree, we used the model of Equation 2 to fit the data from this study to regression equations using $\log_e(\text{dbh})$ in place of $\log_e(D_s)$. The results are summarized in Table 4 and are quite similar to those in Table 3. If this equation is used to estimate the value loss from bear-damaged trees, it is important to remember that the loss in cubic volume recovery (a reduction of 6.4%, as shown by the value of coefficient β_2 in Table 4) is for the first 16-ft butt log only; there is no volume reduction for other logs because bear damage does not extend beyond the first log.

Board Foot Volume Recovery

Gross board foot (bd ft) volume recovery from all logs was 13,070 bd ft. A greater amount of lumber (54.6%) was recovered from the bear sample (because of the larger number of sample logs) with 45.4% produced from the undamaged sample. A small amount of 1-in. lumber was produced in the manufacturing process. For both the undamaged and bear-damaged logs, 8% of the lumber volume produced was 1-in. material.

End trimming to reduce the length of a piece of lumber was commonly done to increase lumber grade in both the damaged and undamaged samples. Decay and splits along the growth ring were primary reasons for end trimming in bear-damaged lumber. Figure 5 illustrates the pattern of lumber defect found in a bear-damaged log. Boards 56 H, I, and J each had 4 ft trimmed, but 56 K had only 2 ft trimmed. In some cases, the trimming resulted in lumber that was too short to be merchantable. These short pieces were removed from the database and were not considered as part of the lumber volume recovered. More bd ft volume was lost to trim in the lumber

Table 3. Statistical results from regression analysis of cubic-volume recovery from bear-damaged versus undamaged trees when the rate of change in recovery with respect to a change in log diameter is assumed to be the same for damaged and undamaged trees. Equation 2 was used to fit the data for damaged and undamaged trees simultaneously. The intercept coefficient was not significantly different from 0 at the 90% confidence limit, so the regression equation was forced through the origin.

Source of variation	Analysis of variance					Regression analysis (adjusted $R^2 = 0.98$)					
	df	Sum of squares	Mean square	F statistic	Significance F	Variable	Coefficient	Estimated coefficient	SE	t statistic	P value
Regression	2	15.365	7.683	1808.921	<0.001	Intercept	β_0	0			
Residual	60	0.25482	0.004247			$\log_e(D_S)$	β_1	0.19833	0.00459	43.199	<0.001
Total	62	15.620				δ	β_2	-0.05926	0.01655	-3.582	<0.001

Table 4. Statistical results from regression analysis of cubic-volume recovery from bear-damaged versus undamaged trees when the rate of change in recovery with respect to a change in diameter at breast height (dbh) is assumed to be the same for damaged and undamaged trees. Equation 2 was used to fit the data for damaged and undamaged trees simultaneously. The intercept coefficient was not significantly different from 0 at the 90% confidence limit, so the regression equation was forced through the origin.

Source of variation	Analysis of variance					Regression analysis (adjusted $R^2 = 0.97$)					
	df	Sum of squares	Mean square	F statistic	Significance F	Variable	Coefficient	Estimated coefficient	Standard error	t statistic	P value
Regression	2	15.350	7.675	1704.859	<0.001	Intercept	β_0	0			
Residual	60	0.27011	0.004502			$\log_e(\text{dbh})$	β_1	0.18490	0.00441	41.918	<0.001
Total	62	15.620				δ	β_2	-0.06369	0.01712	-3.720	<0.001

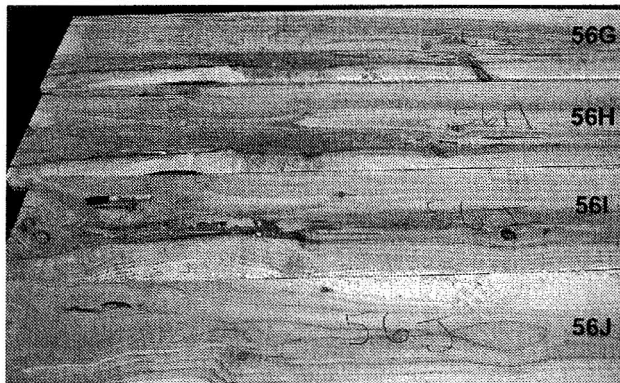


Figure 5. Four pieces of 2 x 10 dimension lumber sawn sequentially from a single bear-damaged log. The image background has been removed for clarity. Note the marking pen included for scale. (Photo by Eini C. Lowell.)

produced from bear-damaged trees (15.6% of the gross tally) than in the lumber produced from undamaged trees (11.2%).

Lumber Quality

Douglas-fir is typically used to produce dimension lumber (2-in.) for use in structural applications, and 92% of the volume manufactured from the logs in this study was produced as dimension lumber. Stain was present in many of the pieces of lumber produced from bear-damaged trees (Figure 5). This is not a grading defect in dimension lumber as it has no effect on the lumber's mechanical properties. However, consumers often regard stain as an indication of lower quality and will generally choose unstained lumber in the retail market. A diagram was prepared for each piece of lumber sawn from the bear-damaged trees to show the extent and character of any defects, including stain. These diagrams showed that defects occurred predominately in the lumber cut from the center of the log and were associated with the annual rings around the time of bear damage. In nearly all cases, the defects extended up the piece a distance of 2-6 ft, a result that is consistent with the

cubic scaling deductions assessed against the damaged logs when they were scaled. For 6 of the 34 damaged logs, the diagrammed defect extended farther than had been estimated during scaling; however, the defect was generally limited to stain (which has no effect on dimension lumber grade), and, in most cases, only one or two boards from the log were affected.

Lumber grade is an expression of perceived value as defined by the grading rules. The primary grade-limiting defects in lumber produced from both damaged and undamaged trees were wide-face knots and wane, neither of which results from bear damage. Bear-damaged trees produced more pieces of lumber with decay and pitch. Table 5 shows the percentages of lumber produced in each grade from both damaged and undamaged trees. The sample from undamaged trees yielded 35% of Select Structural, the highest grade, whereas the sample from damaged trees yielded only 23% in this grade. The same pattern was found for the second-highest grade (No. 1), whereas the bear-damaged trees tended to produce a higher percentage of lumber in the No.2 and lower grades. However, the practical difference is not as great as it might appear, because dimension lumber is often sold as "No.2 (or Standard) and Better," a category that combines the three highest grades. When the grades are combined in this way, the yield from undamaged trees represents 88% of the total lumber produced compared with 80% for damaged trees.

The prices shown in Table 5 are presented for illustration purposes to show potential differences between the damaged and undamaged log samples. Price variations by grade are not always consistent among the grades, and prices can vary daily.

Table 6 summarizes results from a regression analysis on the total value of lumber produced from each log in the damaged and undamaged samples. The dependent variable used in the analysis was DMLT, a measure of the total value of lumber produced per log as determined from the prices shown in Table 5. The analysis suggested that there was no statistically significant relationship between log small-end diameter and DMLT. There was, however, a statistically significant relationship between DMLT and a classification variable measuring whether or not the log was from a damaged tree.

Table 5. Percentage of board foot lumber tally recovered by lumber grade from the 16-ft butt logs of bear-damaged and undamaged trees.

Lumber Size (dimensions in inches)	Lumber Grade () ^a	Price (\$/mbf) ^b	Lumber tally in grade	
			Undamaged	Bear-damaged
			(%).....	
2 × 6 and wider	Select Structural	383	35	23
	No. 1	322	26	13
	No. 2	322	27	45
	No. 3	188	1	8
2 × 4	Economy	126	1	3
	Construction	284	1	<1
	Standard	284	1	<1
1-in. boards, random width	C select	— ^c	0	<1
	D select		1	<1
	2 Common		2	3
	3 Common		4	4
	4 Common		<1	<1
	5 Common		<1	1

^a Source: W/WPA 2005.

^b Prices are from Western Wood Products Association (2007). mbf, thousand board feet.

^c Prices varied from 251 to 452 depending not only on grade but also on board width.

Table 6. Statistical results from regression analysis of log value expressed in dollars per thousand board feet lumber tally as influenced by whether or not the log exhibited bear damage.

Source of variation	Analysis of variance					Regression analysis (adjusted $R^2 = 0.08$)				
	df	Sum of squares	Mean square	F statistic	Significance F	Variable	Coefficient	Estimated coefficient	Standard error	t statistic
Regression	1	4923.646	4923.646	6.200	<0.020	Intercept	β_0	353.993	5.32546	66.4718
Residual	60	47645.768	794.096			Damaged	β_1	-17.9069	7.19141	-2.4900
Total	61	52569.414								
										P value
										<0.001
										<0.020

The overall mean values of lumber produced from undamaged and damaged logs were \$354 and \$336, respectively, a difference of about 5%.

Conclusions

Trees with bear damage do not always exhibit visual signs of damage. In this study, 4 out of 32 logs contained bear damage that was not evident externally. Because most of the trees in this study were damaged at a young age (mean, about 26 years for the 70-year-old trees and about 13 years for the 30-year-old trees), they had time to recover and put on significant diameter growth prior to harvest. Mature wood produced in the outer portion of a log generally has better physical and mechanical properties, and, as such, is more valuable than wood from the center of the log. Because much of the lumber was sawn from the part of the log outside the area where bear damage occurred, the impact of bear damage on the lumber produced was relatively small. This conclusion is specific to the production of structural lumber, however; defects associated with bear damage might well limit the potential of these logs to enter markets not considered in this analysis, such as those for export logs or utility poles.

The difference in log cubic volume recovery (expressed as a percentage) between undamaged and bear-damaged logs was about 6% for all logs in the study. Log diameter had no statistically significant effect on this difference. The lumber was trimmed to remove defects and increase lumber grade regardless of whether it was produced from trees that had been damaged or undamaged, but the percentage of lumber in the highest grades was greater for the sample from undamaged trees than for the sample from damaged trees. Both the volume of lumber recovered and its quality affect log value. In this

study, we found that the butt 16-ft logs from bear-damaged trees were worth about 5% less than the butt logs from undamaged trees. Even so, it seems clear that the optimal harvesting policy, both in terms of log value and in terms of efficient utilization, is to haul the entire butt log to the mill rather than cutting off the damaged portion and leaving it in the woods. Although the value of the damaged portion is lower than in an equivalent undamaged section, most of the lumber recovered from that section can be used, with only a modest reduction in grade and value.

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