Association of ring shake in eastern hemlock with tree attributes

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Abstract

Eastern hemlock (*Tsuga canadensis* (L.) Carr.) is a major or minor associate in many forest types in northeastern North America. There has never been the high level of demand for eastern hemlock lumber that characterizes competing softwoods like white pine and spruce. Nevertheless, periodically interest in greater utilization of eastern hemlock for lumber has encouraged attempts to solve some of the wood utilization problems associated with the species. Ring shake, the longitudinal separation of wood parallel to the growth rings, is one of the more serious problems affecting utilization of hemlock lumber. Ring shake is not allowed in the better and more valuable grades of hemlock boards and it also reduces the grades of dimension lumber. Based on a large sample of trees widely distributed over hemlock's range in the Northeast, we determined whether any tree characteristics are prominent indicators of ring shake in hemlock lumber and estimated shake volume in lumber from trees that were identified as likely to contain shake. A logistic regression (LR) model was used to determine significant factors affecting shake presence (shake percent > 0). For trees recorded as having shake, an ordinary regression model that estimated shake volume was developed. The best LR model to determine presence of shake included the significant predictors bird peck, age, and DBH ($\alpha = 0.05$). This model correctly predicted 77 percent of the validation cases. The best regression model to estimate shake volume in trees having shake included just one significant predictor: DBH. Our results indicate that both older and larger trees are more prone to shake, as well as trees exhibiting bird peck. The ordinary regression equation was only moderately successful at predicting the amount of shake volume.

Eastern hemlock (*Tsuga canadensis* (L.) Carr.), referred to throughout as hemlock, is a major or minor associate in many forest types in northeastern North America. Its native range extends from the Canadian Maritime Provinces, where it is a prominent species, westward through southern Quebec and Ontario, southward to the Lake States. It is found throughout New England, New York, Pennsylvania, the Middle Atlantic States, and southward in the Appalachians into Georgia and Alabama (Godman and Lancaster 1990). Hemlock bark was an important source of tannin for the early leather tanning industry. It was estimated that 8 billion board feet of hemlock timber was cut for its bark in Maine alone from 1760 to 1935, when the industry migrated south and west and chemical-tanning agents replaced tanbark (Coolidge 1963). Little of the timber itself was utilized until the mid 19th century and production of hemlock lumber reached its peak between 1890 and 1910 (Godman and Lancaster 1990).

More recently, gross volume of hemlock growing stock in Canada is estimated at 2 billion ft^3, representing almost 20 percent of the hemlock inventory in eastern North America. The hemlock inventory of growing stock in the United States is estimated to be 8.4 billion ft^3, of which about 80 percent is found evenly divided between the Middle Atlantic States and New England. The remainder is found in the Lake States (14%) and the southern Appalachians (8%) (McWilliams and Schmidt 2000). The pulp and paper industry utilizes 60 percent of the hemlock roundwood production in the United States, the remainder is sawn into lumber. Hemlock bark is the preferred species for landscape mulch in the northeastern United States and thus is an important primary processing by-product.

There has never been the high level of demand for hemlock lumber that characterizes competing softwoods like eastern white pine and eastern spruce. The delivered price of hemlock logs to sawmills in the northeastern United States averages less than half that of white pine, spruce, and even fir. Hemlock has been referred to as an "ugly duckling" in forest manage-

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ment and the "wood of last resort" in utilization (Coolidge 1963, Gardner and Diebel 1996). The wood is coarse and uneven in texture, splinters when worked with tools, is prone to ring shake, and it has uneven moisture content, which causes problems in kiln-drying (Alden 1997). Nevertheless, interest in greater utilization of hemlock for lumber has arisen periodically, encouraging attempts to solve some of these problems (USDA 1973, Gardner and Diebel 1996, Kelty 2000). Interest in hemlock, because it is increasing in abundance in many areas as forests mature and because it is being threatened by the hemlock woolly adelgid (*Adelges tsugae* Annand.), resulted in two recent regional conferences on hemlock ecology and management (Mroz and Martin 1996, McManus et al. 2000).

Table 1. — Summary of variables.

Variable	Description (units)
AGE	Age of tree from growth ring analysis (years)
AREA_YR	Cross sectional area at DBH (in2) divided by tree age (years)
BARK_TYP	Bark type (1 = relatively smooth, 2 = intermediate, 3 = rough heavy plated)
BPK	Coded 1 if occluded bird peck was present on the tree bole; 0 otherwise
DBH	Diameter at breast height (in)
GROWTH	Number of sudden increases/decreases in radial growth over the life of the tree from growth ring analysis (number)
GRS_VOL	Gross volume of tree, lumber tally (board feet)
HT	Total height (ft)
SWEEP	Departure to the nearest inch in the bottom one-third of the tree
SHK_VOL	Volume of lumber containing ring shake (board feet)

Ring shake is one of the more serious problems affecting utilization of hemlock lumber (Gardner and Diebel 1996). Ring shake is the longitudinal separation of wood parallel to the growth rings. According to the standard lumber grading rules applied by the Northeastern Lumber Manufacturers Association (NELMA 1998), ring shake is not allowed in the better and more valuable grades of hemlock boards (C, D, Select, or 1 Common grades). The occurrence and extent of ring shake also reduces the grades of dimension lumber produced for structural framing and construction.

Koehler (1933) suggested that internal stresses caused by sudden changes in diameter growth rates, with emphasis on either greater circumferential growth than radial growth or a reduction in the turgidity of the older tissues, could account for ring shake. Meyer and Leney (1968) concluded that ring shake in western conifers was a naturally occurring defect in standing trees, resulting in a separation of contiguous latewood tracheids along the middle lamella, but could not isolate the causal factors. Wilson (1962) found that both age and diameter were important indicators of shake in a study of hemlock stumps in Massachusetts and attributed the accumulation of yearly growth stresses as a motivating factor for the importance of age. Shigo (1963) found a correlation between the scars and decay resulting from yellow-bellied sapsucker (*Sphyrapicus varius*) damage and the occurrence of ring shake. Sapsuckers drill rows of feeding holes through the outer bark and feed on sap and cambium. Over time, these holes become occluded but the pattern remains visible for many years. Jorgensen and Lecznar (1964) observed the relationship between parenchyma cell dehydration and ring shake in their study of cell structure changes resulting from sapsucker wounds, concluding that internal stress contributes to the formation of shake defects.

Whereas these and other studies have attempted to identify the cause of ring shake, assessments of the occurrence and variability of ring shake have not been conducted on a broad geographical scale. Also, information linking tree attributes to the occurrence of ring shake and shake indicators to the occurrence and extent of shake in lumber manufactured from these trees is needed to improve opportunities for utilization.

This research has two objectives. The first objective is to determine whether any tree characteristics are prominent indicators of ring shake in hemlock lumber. The second objective is to find potential estimators of shake volume in lumber from trees that have been identified as likely to contain shake.

Methods

Data

Data used in this study were collected from 1968 to 1971 as part of a larger study conducted to develop eastern hemlock tree and log grades for estimating lumber grade yields. Because ring shake is one of the more important attributes affecting lumber yields, detection and evaluation of shake was an important aspect of this study. Due to changes in research priorities, analysis of the shake data was not completed at that time. There were a total of 286 trees measured from five states: Georgia, New York, North Carolina, Pennsylvania, and Tennessee.[1] Sampling was conducted on active timber sales located on diverse sites with respect to slope and aspect. Trees were selected over a distribution of diameter at breast height (DBH) classes and butt-log grades. Generally, trees were bucked into 14- or 16-foot sawlogs, but shorter logs were occasionally cut to improve yield. Logs were delivered to cooperating sawmills where they were sawn into 1-inch boards and 2-inch structural dimension. Boards were only cut from those portions of the log that were not likely to yield No. 2 or better dimension grade lumber or when necessary to size the cant. The goal was to saw for optimum lumber grade and width. Lumber was graded green and regraded after it was air-dried. All lumber was identified as to log, tree, and site. The presence of ring shake in lumber was recorded during grading. Potentially important variables used in this study are detailed in **Table 1**.

Statistical analysis

Preliminary attempts at modeling the data through least squares regression failed on multiple fronts due to the restricted ranges of the potential dependent variables, such as 0 to 100 percent for percent by volume of shake and zero to greatest tree volume for volume of shake. Assumptions of normality of the residuals and homogeneity of variances failed in all cases, thus the decision was made to dichotomize shake classes and to model the data in two stages.

A logistic regression (LR) model was used to determine significant factors affecting shake presence (shake percent > 0).

[1] Data also were collected in Maine for 91 trees. However, lumber was only graded green and not when air-dry, as in the other locations; therefore it could not be combined with the other data and was dropped from our analysis.

Once a model was selected, a predicted probability was estimated for each tree. For trees recorded as having shake, an ordinary regression model was developed that identified important predictors for shake volume. All models were developed using SAS®, with $\alpha = 0.05$ and confidence limits (CL) set at 95 percent.

Stage 1

A simple LR model was used to analyze the data. The data set was partitioned into a random 80/20 split, with 80 percent of the data used for model building and 20 percent used for validation and model selection. Due to the large number of variables recorded, potential models were explored using an all subsets procedure within SAS. An initial pool of models containing only significant terms was developed. For each, a Max-rescaled Rsquare (Max-rsquare) statistic was calculated. Then predictions were generated for each observation in the validation set for each model. This allowed the estimation of the proportion of correctly predicted observations to be calculated for each model. Next, the Max-rsquare values and proportion of trees correctly predicted were ranked (separately) and the two ranks added together to arrive at a rank sum score for each model. These rank sums were arranged from lowest to highest, with the lowest scoring model selected as "best."

Variables included in the initial all subsets run were: AGE, AREA_YR, BARK_TYP, BPK, DBH, GROWTH, GRS_VOL, HT, and SWEEP (**Table 1**). Hemlock shake in lumber was categorized into two classes, presence or absence. Potential predictor variables are a mixture of categorical and continuous measures, while the dependent variable is categorical.

An LR model is of the form:

$$\text{logit}(\pi) = \beta_0 + \beta_1 X_1 + \ldots \beta_n X_n$$

where: logit (π) = ln(odds) = ln(π/1 − π); π = probability of "success", here, to the probability of having shake.

The odds reflect the ratio of the probability of success vs. the probability of failure. The transformation ln(odds) is utilized to linearize the parameters of the model.

Stage 2

For the second stage of modeling, the same 80/20 split was used, with the added condition that the trees selected had shake. The same variable pool was utilized in an all subsets run and the best model was selected based on greatest adjusted R-square value and a low Mallow's C statistic.[2] Validation cases were estimated using the model, with mean difference between actual and predicted values (BIAS) and mean absolute percentage error (MAPE) examined for model adequacy. Additionally, residual plots were used to determine homogeneity of variances and normality of the residuals. A logarithmic transformation of the dependent variable was necessary in order to stabilize the variances.

The regression model is of the form:

$$y = \beta_0 + \beta_1 X_1 + \ldots \beta_n X_n$$

$$\text{BIAS} = \frac{1}{n} \cdot \left(\sum_{i=1}^{n} Y_i - \hat{Y}_i \right)$$

$$\text{MAPE} = \frac{100}{n} \cdot \left(\sum_{i=1}^{n} \left| \frac{Y_i - \hat{Y}}{Y_i} \right| \right)$$

Table 2. — Sample tree attributes by state.

State	No. of trees	DBH Mean	DBH Range	Age Mean	Age Range	Tree volume[a] Mean	Tree volume[a] Range
		(in)		(yr)		(BF)	
Georgia	42	22.7	13.1 to 44.3	149.5	75-309	752.5	86 to 2,970
New York	29	16.2	10.1 to 26.0	131.4	105-200	227.9	48 to 593
North Carolina	49	25.7	13.2 to 45.6	191.8	92-491	880.5	58 to 3,432
Pennsylvania	126	17.4	9.0 to 30.7	141.2	46-244	339.8	40 to 1,079
Tennessee	40	24.9	13.4 to 46.3	217.5	79-415	709.4	55 to 2,667

[a]Lumber tally.

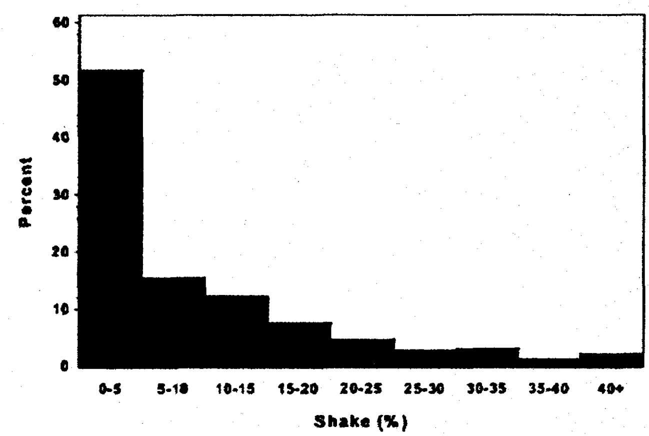

Figure 1. — Distribution of trees by 5 percent shake classes.

Results

Descriptive statistics

Mean tree volume ranged from 227.9 to 880.5 board feet (BF)(lumber tally) and maximum tree volume ranged from 593 to 3,432 BF per tree (**Table 2**). The largest and oldest trees were found in the southern Appalachians. The majority of trees had less than 5 percent shake and about 80 percent of the trees had less than 15 percent shake (**Fig. 1**).

Statistical models

The best LR model was found to be:

$$\ln(odds) = -3.68 + 0.77 \cdot BPK + 0.016 \cdot AGE + 0.12 \cdot DBH$$

All variables were significant: $p = 0.0316$ for *BPK*, $p = 0.0021$ for *AGE*, and $p = 0.0067$ for *DBH*. This model correctly predicted 77 percent of the validation cases.

The best regression model was:

$$\ln(SHAKE\_VOL) = 2.57 + 0.055 \cdot DBH$$

alternatively,

$$SHAKE\_VOL = 13.06e^{0.055DBH}$$

[2] Consult Neter et al. 1996 for additional information on model building selection criteria.

Table 3. — Logistic regression parameter estimates, odds ratios, 95 percent CL and p-values.

Parameter	Estimate	95% Wald CL			
		OR	LCL	UCL	p
Intercept	−3.67	--	--	--	--
BPK	0.77	2.617	1.07	4.39	0.0316
AGE	0.16	1.016	1.01	1.03	0.0021
DBH	0.11	1.12	1.03	1.22	0.0067

DBH was a significant predictor, with $p < 0.0001$. Residual plots indicated no problems with homogeneity of the residual variances.

Discussion

Ring shake is a serious wood utilization problem in hemlock because of its frequency of occurrence and potential for degrading a high proportion of lumber when it is present. Results from this study indicate that ring shake occurs over a wide range of site conditions and geographic locations that covered a large part of hemlock's native range in the eastern United States. This result supports Wilson's (1962) conclusion that ring shake in eastern hemlock is not strongly linked to site attributes and location.

Occluded bird peck (BPK) on the tree bole was an indicator of ring shake in lumber. The odds of a tree with bird peck having shake were slightly greater than 1 to 4.4 times (95% CL) the odds of a tree without bird peck having shake (**Table 3**). For any given combination of AGE and DBH, the effect of BPK is an increase in the probability of shake. Increases in either AGE or DBH also increased the probability of shake (**Fig. 2**). For each additional 1-inch increase in DBH, the estimated odds of containing shake increased by about 3 to 22 percent (95% CL). Each additional year of age increased the odds of shake by 0.6 to 2.7 percent (95% CL). On an additional decade growth basis, the odds increased by 6 to 30 percent.

As an example, consider a tree with values for DBH and AGE very near the means, that is a tree with 20-inch DBH and 150 years old, and BPK = 0. The estimated probability of this tree having shake can be calculated directly from

$$\hat{\pi} = \frac{\exp(-3.68 + 0.77 \cdot BPK + 0.016 \cdot AGE + 0.12 \cdot DBH)}{1 + \exp(-3.68 + 0.77 \cdot BPK + 0.016 \cdot AGE + 0.12 \cdot DBH)}$$

$$\hat{\pi} = \frac{\exp(-3.68 + 0.77(0) + 0.016(150) + 0.12(20))}{1 + \exp(-3.68 + 0.77(0) + 0.016(150) + 0.12(20))} = 0.75 \text{ or } 75\%$$

This equation results from exponentiating both sides of the ln(odds) equation and solving algebraically for $\hat{\pi}$. Next, consider an example with the same AGE and DBH as previous, but with BPK present. We have:

$$\hat{\pi} = \frac{\exp(-3.68 + 0.77(1) + 0.016(150) + 0.12(20))}{1 + \exp(-3.68 + 0.77(1) + 0.016(150) + 0.12(20))} = 0.87 \text{ or } 87\%$$

These results indicate that both older and larger trees are more prone to shake. This supports the findings of Wilson (1962). Trees exhibiting bird peck also have increased probabilities for shake, providing more empirical support for both the hypotheses of Shigo (1963) and Jorgensen and Lecznar (1964).

The ordinary regression determined that for trees with shake, DBH was the only significant variable in the best model. Back transforming this model indicated that DBH was related exponentially to shake volume. Each increase of 1 inch in DBH led to an increase of from 4 to 7 percent (95% CL) in BF shake volume.

This model was only moderately successful at explaining the variability in the data, with an r^2 value of 0.24. The model based on the log-transformed shake volumes had BIAS ranging from −0.22 to 0.29 (95% CL), indicating a good fit of the model for the validation data. MAPE for the transformed model ranged from 14 to 28 percent (95% CL). Transforming back to original units, the exponential model under predicts lumber shake volume to from 4 to 41 BF (95% CL). MAPE for the exponential model was high, ranging from 53 to 140 percent (95% CL).

Although the ordinary regression equation was only moderately successful at predicting the amount of shake volume, it is informative to know that DBH is a factor for trees susceptible to shake, even if it is a widely varying relationship. There are certainly other factors contributing to both the presence and volume of shake. While the variables identified in the LR model are fairly efficient at predicting shake, a different pool of variables, possibly combined with a non-linear model form, may be the approach necessary to model shake volume.

Conclusions

The two-stage modeling approach was useful to address the threshold nature of trees with and without shake. By first developing a model for shake presence, we were able to focus later on cases with shake. This allowed a second stage of model development. The given models could quite easily be computed in the field with something as simple as a programmable calculator. Alternatively, nomograms are presented in **Figure 3** that give estimates of the percent chance that the tree has shake for a given age, DBH, and presence/absence of birdpeck. The ranges given are expected ages and sizes in a commercial forest. Should this percentage exceed 50 percent, a person in the field could then utilize the regression model for shake volume to estimate the volume of wood in the tree with shake, and make any needed deductions.

There are several recommendations for forest managers with interest in growing and harvesting hemlock. Hemlock grown to large diameters and older ages will have an increased probability of developing shake. A direct consequence for susceptible large-diameter trees is an exponentially larger amount of shake. Indirectly, susceptible older trees, which are often larger, may also have exponentially larger amounts of shake. If the increase in shake volume is offset by gains in overall gross volume, this is not a problem. If not, planning for earlier removals of hemlock from stands may be required. Lancaster (1985) recommends regenerating even-aged hemlock stands when the average diameter is between 16 and 18 inches, which implies a rotation age of about 120 years in the Northeast. From **Figure 3**, in trees with no birdpeck, the probability of ring shake is between 50 and 60 percent, and considerably higher for trees with birdpeck, 70 to 75 percent. Predicted shake volume for trees in the diameter

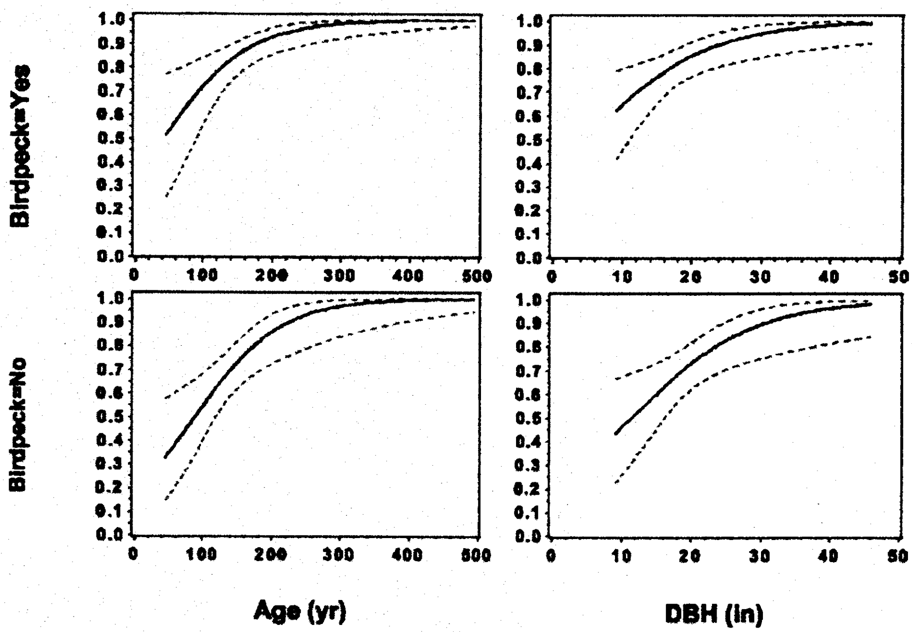

Figure 2. — Effect graphs for LR Model. Other variable held at mean value, with mean(Age) = 145.8 years and mean(DBH) = 19.3 in. Dashed lines indicate 95 percent prediction bands. Figures demonstrate the effect of increasing one variable while holding the others constant.

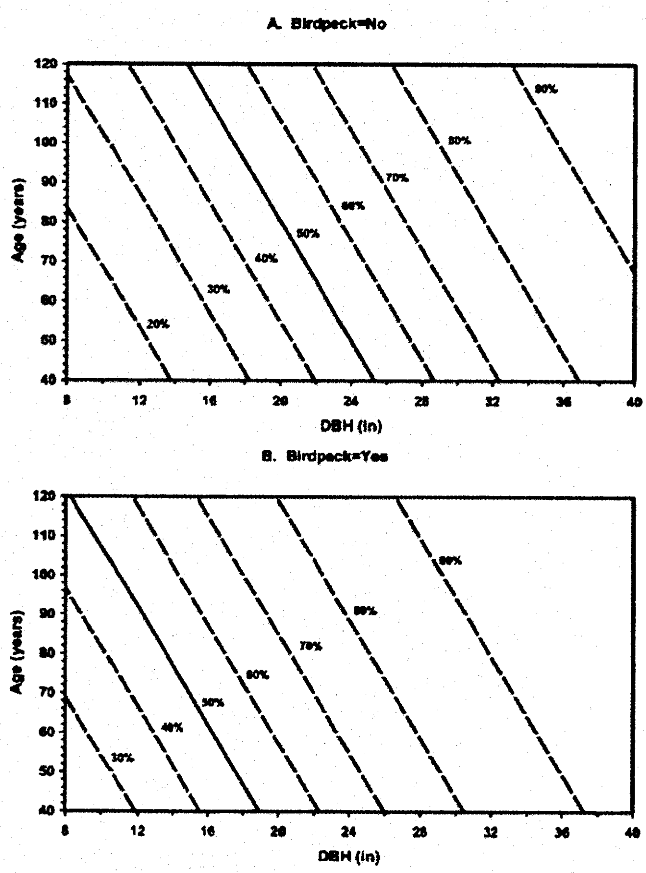

Figure 3. — Nomograms to estimate predicted percent chance of tree having shake. Dark solid line indicates 50 percent cutoff. Trees left of the line would be estimated to not have shake, while those to the right would be estimated as having shake.

range with shake is between 25 to 50 BF or about 10 to 15 percent of volume.

Management goals may include aesthetics, wildlife habitat, or biological diversity as equally important or more important than timber production. Hemlock stands are superior winter cover for white-tailed deer in the northern part of their range, providing both shelter and browse (Reay et al. 1990). Managers need to recognize that these other goals may have negative implications for quality hemlock timber production if they require that hemlock be managed on longer rotations for larger diameters. Whichever the goals, information about the probability of shake and estimates of volume loss due to shake can be helpful in hemlock utilization.

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