RESEARCH ARTICLE

J. For. 115(5):397–405
https://doi.org/10.5849/jof.2016-026R1

silviculture

Relationship between Tree Value, Diameter, and Age in High-Quality Sugar Maple (*Acer saccharum*) on the Menominee Reservation, Wisconsin

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Guidelines for managing sugar maple-dominated forests by the single-tree selection method are well established and widely adopted. The forests of the Menominee Tribe in Wisconsin provide an opportunity to validate current guidelines by testing tree value and size/age relationships in forests that have substantially older and larger high-quality trees than can be found through the northern region. We harvested grade 1 sugar maple trees across a wide spectrum of ages and diameters, which we then manufactured into veneer, sawlogs, cants, and hardwood/pulpwood bolts to determine tree value. Tree value continued to increase with increasing dbh, but when the effect of tree age on value was discounted, the value of trees older than 100 years dropped precipitously toward zero. Thus, managing trees to maximize diameter and quality within genetic and site potential and harvesting at about 100 years will produce high-value grade 1 trees in the range of 24 to 30 in. dbh.

Keywords: sugar maple, uneven-aged, tree value, utilization, Menominee

Forest managers are interested in how tree value changes, in part to determine when it is best to harvest trees that are capable of producing quality, high-value sawtimber and veneer logs. Tree diameter is one of several factors that determine the type of forest product, i.e., pulp, saw or veneer log, and tree volume, which collectively influence potential tree value (Rast et al. 1973, Husch et al. 2002). Tree diameter is also a key attribute that is used to manage forests, especially in the single-tree selection (STS) silvicultural system, where it is used to schedule management activities and to set desired structural targets such as maximum tree dbh and residual basal area. Maximum tree diameters in management are often determined by financial considerations. In general, dominant and codominant trees in a stand grow larger in diameter over time and, therefore, potentially become more valuable. But time is a two-edged sword because it takes time to grow large diameter trees for high-value products, and there is a financial cost of time; in addition, the longer a tree remains in the forest increases its risk of experiencing volume or value loss due to damage, wood decay, wood discoloration, or death (Nordin 1954, Shigo 1966, Erickson et al. 1992). In sugar maple (*Acer saccharum*), veneer and whitewood lumber are some of the highest valued products, next to figured grains such as birdseye and curly wood, that can dramatically increase tree value (Germain et al. 2015). The salient question then is: "Is there an age or diameter at which tree value is highest?"

There are nearly 51 million ac of the maple-beech-birch forest type in the Northern Region of the eastern United States, which represents 29% of all forestlands in that area (Oswalt et al. 2014). This forest type is also prominent in eastern Canada. The northern (tolerant) hardwood forests dominated by sugar maple are most often managed by the uneven-aged method of STS (e.g., Anderson et al. 1990, Nyland

Received July 29, 2016; accepted January 5, 2017; published online February 2, 2017.

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Acknowledgments: *We thank Larry Waukau, Marshall Pecore, Dan Pubanz, and all other employees of the Menominee Tribal Enterprises who helped to develop and implement this research. These fine men were instrumental in getting the field data collected, the sample trees logged and to the mill, the veneer logs sold, and the sawlogs manufactured into lumber. It was a pleasure working with them. We thank the Menominee people for allowing us to conduct this research on their land. This research was funded by the USDA Forest Service, Northeastern Research Station, and Northeastern State and Private Forestry through a grant with the University of Missouri. Al Steele, John Baumgrass, and Jan Wiedenbeck were helpful in their reviews of the study proposal and in their support in the administration of this project.*

1996, Ontario Ministry of Natural Resources 1998, Kern et al. 2014, Leak et al. 2014). Setting maximum tree diameter (dbh) at maturity is an important part of STS, which also has financial consequences as it sets limits on the potential value of harvested trees. Sugar maple is a major dominant species on high-quality sites throughout this region and accounts for a significant proportion of growing stock volume (Oswalt et al. 2014). The majority (58%) of this forest type is 60–100 years old and is in the sawtimber size class. Important forest management decisions will be made in the near future concerning the timing of harvesting this vast resource.

Current guidance is to manage northern hardwoods by STS with maximum diameters set between 18 and 24 in. dbh (e.g., Leak et al. 2014). Arbogast (1957), a pioneer in uneven-aged management of northern hardwoods, considered sugar maple to be economically mature between 20 and 24 in. dbh and set the upper limit on mature tree diameter at 24 in. dbh for the objective of sustainably producing an abundance of high-quality timber. This guide is still widely used for STS in northern hardwoods (Ontario Ministry of Natural Resources 1998, Menominee Tribal Enterprises [MTE] 2012, Kern et al. 2014, Leak et al. 2014). The Wisconsin Department of Natural Resources (2016) silvicultural guidelines recommend 24 in. as a maximum dbh for sugar maple managed to optimize timber quality and quantity under the STS system but allow for a variance in diameter from 18 to 30 in. to accommodate differences in site quality and management objectives. Studies used to derive maximum dbh in STS and understand how economic value varies with tree size were conducted in forests that were recovering from a period of exploitative logging in the Lake States and Northeast (e.g., Argonne Experimental Forest) or those considered to be unmanaged old-growth forests (e.g., Dukes Experimental Forest) (Kern et al. 2014). In addition, current analyses to link optimal financial return to structural attributes of trees in stands managed by the STS method do not account for grade variation in sawlog classes, and most do not factor into value any contributions from veneer logs or proportion of whitewood as they vary by tree diameter, age, and vigor (e.g., Adams and Ek 1974, Niese and Strong 1992).

The forests of the Menominee Tribe in Wisconsin offer a unique opportunity, compared with the forest conditions used in previous studies, to verify whether the relationship between tree value and tree attributes in sugar maple is consistent regardless of stand management history. Menominee forests have been sustainably managed for 160 years, and the STS is the primary management system used in their northern hardwood stands (Pecore 1992, Burgess 1996, MTE 2012). Trees of high quality are grown to large sizes (>30 in. dbh) and advanced ages (>300 years) on the Menominee Reservation. This permits a rare opportunity to study the effects of larger tree size and advanced age on timber quality and value than has been previously considered (Mendel et al. 1973, Godman and Mendel 1978).

The purpose of this study is to determine how the value of sugar maple varies by tree characteristics. We evaluated the relationship between tree diameter, height, age, and other measures of tree vigor on product recovery and total tree value. The study focused on the highest quality sugar maple (grade 1 trees according to Hanks 1976a) growing on high-quality, excellent site productivity habitat types, i.e., *Acer/Fagus/Adiantum* (AFAd) and *Acer/Hydrophyllum* (AH) (Kotar et al. 1988). Specific objectives were to determine what value was gained or lost in growing sugar maple to large diameters in stands managed by the STS method on Menominee Tribal lands by modeling the production of veneer, grade sawlog, whitewood lumber, and tree value based on tree size, age, and vigor attributes. We evaluated the array of forest products currently manufactured and marketed by MTE. For example, MTE sells veneer logs by competitive bid, and sawlogs are processed at their mill.

The MTE approach to forest management is tempered by their strong land ethic and molded by a vision of providing for future generations that is rooted deeply in their cultural and spiritual heritage (Huff and Pecore 1995, Davis 2000, Trosper 2007, 2012, Watts 2016). This does not preclude, however, having a major forest management objective of maximizing timber growth, quantity, and quality (MTE 2012). This is done in a way that improves diversity, promotes community stability and economic development, provides quality wildlife habitat, and protects water quality, cultural values, and esthetics. The Menominee operate their mill not only for profit but also to provide employment for their people, to provide a place to train and develop skills in the workforce and community stability, and to promote families and enhance tribal self-determination (MTE 2012). The sawmill is a major source of employment for the Menominee, and for the foreseeable future, sawlogs will be processed locally by the Menominee. Thus, we determined tree value by competitive bidding for veneer logs and grading lumber and other by-products cut from logs in their mill. Ultimately, this research will provide input to guide STS prescriptions for managing sugar maple forests owned by the Menominee people.

Methods

The study took place on the Menominee Indian Reservation in northeastern Wisconsin in 2000–2001. The Menominee have 220,000 ac of forestlands of which one-third are northern hardwoods where sugar maple is the most common species and accounts for 23% of the standing sawlog volume. Sugar maple (northern hardwood) is the desired cover type on the better habitat types ranging from *Acer/Tsuga/Fagus/Dryopteris* to AH (MTE 2012) along a moisture and fertility gradient. We sampled sugar ma-

Management and Policy Implications

Forest research conducted on Indian lands often provides different perspectives and conditions that give new insight to forest management. In the case of the Menominee Tribe of Wisconsin, we were able to expand our understanding of tree value and how it changes for much older and larger sugar maple trees than were studied in previous research. The results of this research in many ways confirm existing recommendations for tree size and age related to financial maturity. We did find that absolute tree value increased with ever-increasing tree dbh beyond 30 in.; however, there is a financial cost to growing trees for 300 years to obtain large dbh. This is important for policy and management because it is crucial for managers to practice silviculture to promote the highest diameter growth rates possible given tree genetics and site productivity to maximize tree dbh at harvest. High-grade sugar maple can be grown to 24->30 in. dbh on productive sites in 100–150 years, and this should help to maximize financial returns. Careful logging operations are vital to avoid injury to crop trees that can lead to the development of discolored wood and decay, serious grade defects, and other sources of value loss.

Table 1. Distribution of sugar maple study trees among management compartments on the Menominee Reservation.

Compartment	No. of trees	Legal description	Habitat type
203	14	T 30 N, R 15 E	AFAd
224	27	T 28 N, R 15 E	AFAd
231	13	T 28 N, R 15 E	AFAd
332/336	6	T 29 N, R 13 E	AH

ple trees on AFAd and AH types. AFAd types are characterized by loamy soils that are rich to very rich in nutrients and have a rich moisture regime. AH types are the most productive sugar maple sites on the Menominee reservation and are characterized by silt loams and loams that are rich to very rich in nutrients and rich to very rich in moisture regime.

The number of sample trees ($n = 60$) was based on Hanks (1976b). We selected grade 1 (Hanks 1976a) sugar maple trees where they occurred in stands within four management compartments if they were high in vigor and free from any signs of damage caused by biotic agents or abiotic disturbances (Table 1). The sample of tree grade 1 sugar maples had a limited range of defect and decay problems.

Field Data Collection

In October 2000, trees were selected and numbered, habitat type was determined, dbh was measured, and trees were classified by crown class (Smith et al. 1997), tree vigor (1, 2, 3, and 4 in Supplemental Table S1[S]) and bark vigor (high, medium, and low according to Anderson and Rice 1993). Trees averaged 21.7 ± 5.3 in. dbh (range, 13.6–33.3 in.) and 154 ± 52.6 years in age (range, 76–297 years).

The sample trees were felled and bucked into 8- to 16-ft logs in the fall of 2000. A unique number was painted on each log end that identified the tree and log position in the tree. Logs were bucked to maximize log grade. During November 2000, the logs were delivered to the MTE mill at Neopit, Wisconsin, where they were scaled and graded. The sample of trees produced 304 logs, of which 223 were milled as sawlogs and 81 logs were sold as veneer. The total gross scale (Scribner Decimal C Scale) for all study logs was 31,580 boardfeet (bf) and the net scale was 30,620 bf. Veneer logs accounted for 27% of the total sample of logs, but comprised 37% of the total net volume. Veneer logs totaled 11,460 bf net log scale, and there was 19,385 bf net log scale of sawlogs. Each tree produced hardwood bolts and pulpwood from upper limbs and topwood. Tree age was determined for each tree from a cross section removed from the stump based on tree-ring count after surfaces were prepared to permit observation of cellular detail.

Discolored and Whitewood Proportions

The proportion of discolored to whitewood in sugar maple trees is important because discolored lumber is substantially less valuable than white-colored maple lumber. Therefore, we measured the diameter of discolored wood at both ends of the log and calculated the volume of discolored wood using the formula:

$$[(S + 1) \times (L + 1) \times LD] \div 15$$

where S is the average small end diameter of the discolored wood (inches), L is the average large end diameter of the discolored wood (inches), and LD is the length of the defect (feet).

Milling and Lumber Data

In January 2001, 223 sugar maple sawlogs were processed through the mill. A Wisconsin Department of Natural Resources milling specialist assisted the head sawyer to maximize value recovery by producing larger-sized white wood boards using taper sawing techniques on larger diameter logs. People were positioned at the headrig and edger to record log numbers and mark individual boards produced from each log. Boards were sawn from logs down to the discolored core, which was left as a cant. Boards were edged to upgrade their value. After edging, each board was graded by a certified lumber grader using the Northern Hardwood and Pine Association grades (Table 2) (Rast et al. 1973, National Hardwood Lumber Association 2014). Lumber data were recorded for each log including log number, sawing order, board thickness, and net volume by grade. For each cant, we recorded the log number, cant thickness, width and surface measure (in inches), and net volume in board feet. Chips and sawdust from all logs were collected and weighed together.

Calculating Total Tree Value

Each study tree was manufactured into veneer logs, dimension lumber, cants, and hardwood and pulpwood bolts, and its value was determined in US dollars for the year 2000. We determined the value of veneer logs by selling them through a competitive bid. The highest bid for the veneer logs was $19,943.00, which was substantially higher than their estimated lumber value of $10,182.50. Slightly more than half of the veneer logs were butt logs, and one-third came from the second log position.

We established a value for sawn lumber using hard maple lumber prices obtained from the *Hardwood Market Report*[1] (see Supplemental Table S2) for the week the logs were sawn at the mill. A total of 14,114 bf millscale was sawn from the 223 sugar maple logs, of which 39% was premium white wood grades valued at $8,855.46, and the remainder made hard maple and sap grade (discolored wood) lumber valued at $7,982.75. Cant value was determined using $280/mbf and totaled $1,399.58. Hardwood and pulpwood bolts contributed a minor amount to total tree value. Total volumes of 264.8 cu ft of boltwood valued at $251.60 and 637.3 cu ft of pulpwood valued at $597.50 were produced. To compare tree values at a common time for trees that varied in age, we discounted total tree value for the age of the tree at a rate of 3%.

We used binary logistic regression to determine how well individual tree characteristics performed in predicting the probability that a sugar maple tree would have at least one veneer log. We used the cumulative logit model for ordered categories to model the probability of various log grades (veneer and grade 1 sawlog, grade 2 sawlog, and grade 3 sawlog) for each of the first three log positions (Allison 2001). We evaluated a number of models that included various combinations of tree diameter (dbh), age, merchantable height, crown class, tree vigor, and bark vigor. The likelihood ratio was used to identify significant models ($\alpha = 0.05$) and Akaike's information criterion corrected for small sample sizes (AIC_c) was used to compare models and identify the best, most parsimonious models. Linear regression was used to predict the volume and proportion of total log or tree volume of both discolored and white wood based on tree age, dbh, or small end log diameter. It

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[S] Supplementary data are available with this article at http://dx.doi.org/10.5849/jof.2016-026R1.

Table 2. Evaluation of models to predict the probability of log grade for the first log of tree grade 1 sugar maples.

Model[a]	Likelihood ratio test Pr > χ^2	AIC_c	ΔAIC_c	First β_0	Second β_0	$\beta_1 X_1$	$\beta_2 X_2$	$\beta_3 X_3$	$\beta_4 X_4$	$\beta_5 X_5$
AGE	<0.0001	52.1	0.0	7.728	11.956	−0.038				
AGE + DBH	<0.0001	52.4	0.3	9.964	14.226	−0.029	−0.157			
AGE + BV	<0.0001	53.3	1.2	7.936	12.300	−0.040	0.988			
AGE + TV	<0.0001	53.4	1.3	8.738	13.015	−0.038	−1.236			
AGE + BV + TV	<0.0001	54.2	2.1	9.293	13.743	−0.041	1.194	−1.552		
AGE + DBH + BV	<0.0001	54.4	2.3	9.742	14.087	−0.032	−0.132	0.677		
AGE + DBH + TV	<0.0001	54.6	2.5	10.168	14.441	−0.030	−0.134	−0.629		
AGE + DBH + BV + TV	<0.0001	56.3	4.2	10.083	14.493	−0.035	−0.086	0.936	−1.096	
DBH	<0.0001	58.1	6.0	8.957	12.597	−0.333				
DBH + AGE + TV + BV + HT	<0.0001	58.3	6.2	9.870	14.307	−0.099	−0.035	−1.089	0.903	0.007
DBH + BV	<0.0001	60.3	8.2	9.164	12.821	−0.338	−0.280			
DBH + TV	<0.0001	60.4	8.3	8.937	12.587	−0.339	0.205			
DBH + BV + TV	<0.0001	62.6	10.5	9.162	12.840	−0.349	−0.322	0.314		

Log grades are 1 = veneer or grade 1 sawlog; 2 = grade 2 sawlog; and 3 = grade 3 sawlog. AIC values are corrected for small sample size ($n = 60$). The probability of the first log being a grade 1 log is computed with the logistic model using the first intercept (Equation 1), the probability of the first log being either a grade 1 or 2 log is computed with the logistic model using the second intercept (Equation 2), the probability that the first log is a grade 2 log is calculated by subtracting the probability from Equation 1 from the probability from Equation 2, and the probability of the first log being a grade 3 log is determined by subtracting Equation 2 from 1.0. A grade 1 log in this analysis is a veneer or grade 1 sawlog, a grade 2 log is a grade 2 sawlog, and a grade 3 log is a grade 3 sawlog.

[a] Where models are of the form $P = [1 + \exp[-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n)]]^{-1}$ and DBH is dbh measured in inches; AGE is tree age (years); TV is tree vigor (see Supplemental Table S1) (coded 1 for good and 0 for fair), BV is bark vigor (coded 1 for high and 0 for medium), and HT is merchantable height (feet).

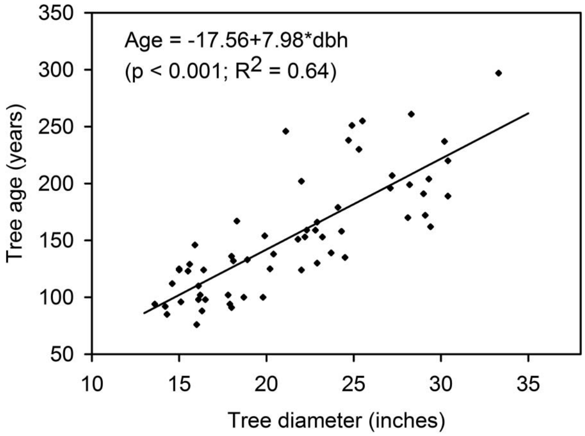

Figure 1. Relationship between tree diameter (dbh) and age for tree grade 1 sugar maple on the Menominee Reservation study site.

was also used to evaluate the relationship between tree value and dbh and age.

Results and Discussion

Sugar Maple Tree Data

In general, age increased with increasing diameter (dbh) in sugar maple (Figure 1), as did the variability in tree age. Dbh was significantly related to age ($P < 0.0001$), and dbh explained about 64% of the variation in age. Kenefic and Nyland (1999) also found a significant relationship between dbh (trees <27 in. dbh) and age (trees <120 years) in sugar maple trees in stands managed by STS in central New York. This is an important relationship because dbh is often used as a surrogate for managing uneven-aged stands. The dbh-age relationship also provides a strong link between time-sensitive processes such as diameter growth, wood production, and decay development that can be translated into easily measurable tree attributes that are useful in managing forests. In addition, tree and log quality and volume and hence present and future tree value are determined, in large part, by tree diameter and diameter growth (Mendel et al. 1973, Godman and Mendel 1978, Niese et al. 1995). Hence, a strong dbh-age relationship facilitates estimates of current and future quality and value in trees.

The distribution of log grade by log position within a tree is summarized in Figure 2. Veneer and grade 1 sawlogs dominated in the first log position as tree diameter (dbh) increased up to 24 in., above which grade 2 and 3 logs predominated. In the second log position, more than half of the logs were veneer and grade 1 sawlogs for most diameter classes. Veneer and grade 1 sawlogs were uncommon in the third log and higher positions; however, they were more likely to occur in larger dbh trees (≥24 in.). These results are in line with the generalization that log grade in the first log position increases with increasing tree diameter, especially in the dbh range of 12 to 24 in. (Rast et al. 1973, Smith et al. 1979). Hence, tree value can be expected to increase also because tree grade and log grade are the most important determinants of tree and log value in eastern hardwoods (Mendel et al. 1973, Godman and Mendel 1978, Smith et al. 1979). In larger dbh (i.e., 24 in.) sugar maples, higher log grades in the upper log positions do not produce enough value to compensate for loss of grade in the first log.

Probability of a Tree Having Veneer

The probability that a tree had at least one veneer log was significantly related to either dbh or age based on the likelihood ratio test (see Supplemental Table S3). The set of best models included those with either dbh or age based on a comparison of each model's AIC_c (Burnham and Anderson 1998). The model with dbh and bark vigor produced the lowest AIC_c. The probability of having at least one veneer log increased with increasing tree dbh from 13 to 33 in., with increasing age from 75 to 300 years, and with increasing bark vigor (see Supplemental Figure S1). In application, models with dbh are probably preferred over age models because diameter is easier to measure than age. Germain et al. (2015) also found

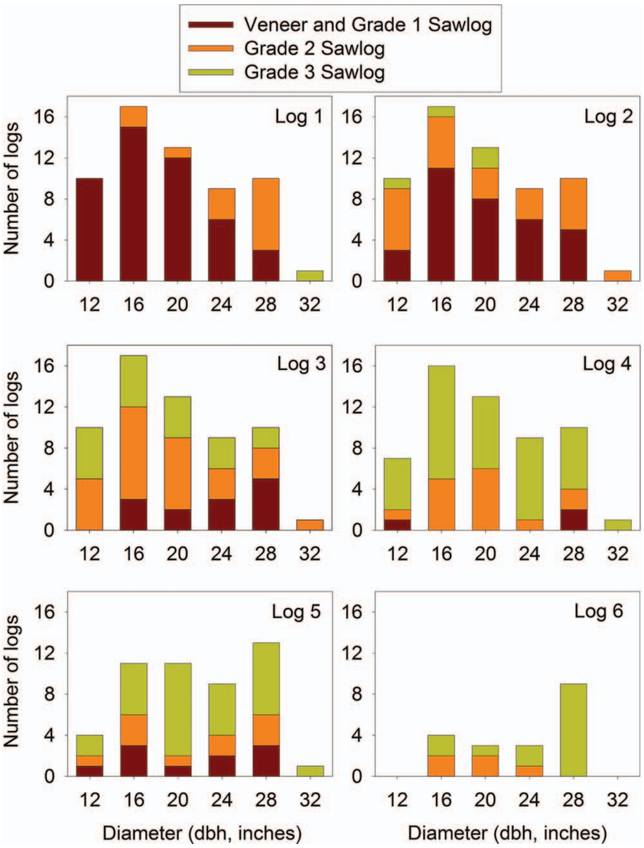

Figure 2. Distribution of logs by grade for the first six log positions in tree grade 1 sugar maple on the Menominee Reservation study site.

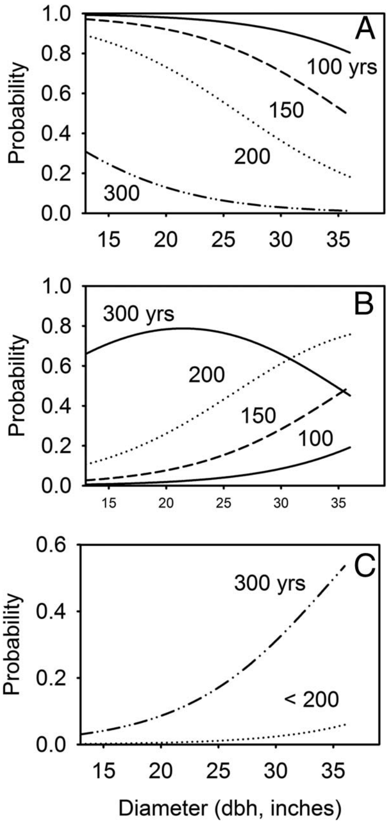

Figure 3. Probability of being a specific grade log in the first log position in tree grade 1 sugar maple based on tree diameter (dbh, in.) and tree age (years). A. Probability of being a veneer or grade 1 sawlog. B. Probability of being a grade 2 sawlog. C. Probability of being a grade 3 sawlog. Probability curves are derived from the equation for model AGE + DBH in Table 2.

that indicators of tree vigor such as bark type and crown ratio were significantly related to the amount of discolored wood in sugar maple and hence were good predictors of log grade and value.

Probability of Log Grade by Log Position in the Tree

Tree age, dbh, tree and bark vigor, and merchantable height were used to predict the probability of log grade in the first log position. In this analysis, grade 1 logs were primarily veneer logs but also included a few grade 1 sawlogs. Grade 2 and 3 logs were grade 2 and 3 sawlogs, respectively. All models tested were significant (Table 2, $\alpha = 0.05$). However, models that included combinations of dbh and one or more measures of vigor did not perform as well as models with age and vigor or age and dbh alone according to a comparison of model AIC_c values (Burnham and Anderson 1998).

The probability that the first log is a veneer or grade 1 sawlog is high (near 100%) for trees that were between 13 and 18 in. dbh, but the probability declined with increasing tree diameter, to a low of <20% for trees greater than 30 in. in dbh (Table 2; see also Supplemental Figure S2). Conversely, the probability that the first log is a grade 2 or 3 sawlog increased with increasing diameter, and probabilities were highest for trees with diameters >30 in.. For example, there is about a 70% chance that the first log of a 33-in. tree is a grade 2 sawlog. Similar patterns were observed between the probability of log grade in the first log and tree age (see Supplemental Figure S2). Probabilities of the first log being veneer or a grade 1 sawlog were >85% for maples that were <150 years old. Probabilities of the first log being a high-quality log declined sharply in trees that were older than 150 years.

The probability of the first log being veneer or grade 1 sawlog was high across a wide range of tree diameters for trees that were about 100 years old (Figure 3A). Sugar maples that were 200 years old had substantially lower probabilities of having a veneer or grade 1 sawlog as the butt log than 100-year-old trees, and this difference increased as tree dbh increased. Trees that were 300 years old had low probabilities of having high-quality butt logs almost regardless of dbh. The probability that the first log was a grade 2 sawlog continually increased with tree dbh for maples that were 200 years old or younger, and the probability of being a grade 3 sawlog remained low for diameters up to 35 in. (Figure 3B). The probability of being a grade 2 sawlog peaked in the 20–25 in. dbh range for 300-year-old maples. In these old trees, the probability of having a grade 3 sawlog as a first log increased rapidly for trees with diameters greater than 25 in. (Figure 3C).

We evaluated the same set of logistic regression models to predict the probability of a log being a certain grade for the set of second logs using combinations of tree dbh, age, and bark and tree vigor. We found that none of the models tested was significant ($\alpha = 0.05$) (see Supplemental Table S4) based on the likelihood ratio test. In the second log position, the distribution of veneer and grades 1 and 2 sawlogs was fairly consistent across the range of dbh in this study (Figure 2), and this contributed to the lack of significance in our probability models. Similarly, models predicting the probability of log grade for the third log position were generally not significant (see Supplemental Table S5). Diameter (dbh) was the only model to show significance ($\alpha = 0.05$) in predicting the probability of log grade in the third log position. The probability of third logs being veneer or grade 1 sawlogs increased with increasing dbh from a low of 11% to nearly 50% for trees with dbh approaching 33 in.. This may be due in part to minimum small end diameter specifications for veneer and grade sawlogs; i.e., you need big trees to have third logs with enough diameter to meet grade specifications. Others have been successful in predicting log grades within a tree using dbh, log position, and tree grade and merchantable height using linear discriminant analysis and other modeling approaches in yellow-poplar (*Liriodendron tulipifera*) (Hilpp and Pelkki 2003), sugar maple, and other eastern hardwood species (Reed et al. 1987 Yaussy et al. 1988).

Table 3. Linear regressions to estimate volumes and proportions of discolored wood or whitewood in sugar maple logs that were manufactured from grade 1 trees on the Menominee Reservation.

Response variable	β_0	β_1	*P* Value	r^2
DW volume (bf log scale)	−96.4796	6.841 · dbh	<0.0001	0.435
DW volume (bf log scale)	−30.7561	0.5372 · age	<0.0001	0.264
DW proportion of gross log volume	0.05097	0.02066 · dbh	<0.0001	0.176
DW proportion of gross log volume	0.2021	0.00192 · age	<0.0001	0.150
DW volume (bf log scale)	−107.9245	10.8231 · sed	<0.0001	0.625
DW volume (bf/tree)	19.4652	5.7318 · dbh	0.0093	0.110
DW volume (bf/tree)	44.667	0.6366 · age	0.0036	0.137
WW volume (bf/tree)	28.4878	2.984 · dbh	0.0260	0.083
WW volume (bf/tree)	60.7448	0.2069 · age	0.1268	0.040
WW proportion of tree volume	0.4647	−0.00296 · dbh	0.3562	0.015
WW proportion of tree volume	0.4606	−0.000386 · age	0.2279	0.025

Estimates are based on tree dbh (inches), age (years), or small end log diameter (sed in inches). DW, discolored wood; WW, whitewood.

Discolored and Whitewood Lumber Volume and Proportions

About 40% of the total volume milled from all sugar maple trees made whitewood lumber grades. Discolored wood volume (bf log scale) for each log was significantly related to tree dbh or age (Table 3). On average, the volume of discolored wood in a log increased with dbh and age, regardless of log position in the tree. Discolored wood volume was nonexistent in 13-in. dbh trees, but increased to more than 100 bf in trees >30 in. dbh or >250 years old. Variability in discolored wood volume was noticeably higher in logs from trees with dbh >27 in. and in trees older than 150 years. The proportion of discolored wood volume to gross log volume was also significantly related to tree dbh and age (Table 3). The proportion of discolored wood increased slightly in larger dbh and older trees, but there is much variability in these proportions and dbh and age only explained about 15% of the variation in the discolored wood proportion. Similarly, total volume of whitewood was significantly related to tree dbh but had a nonsignificant relationship to age (Table 3). As tree dbh increased so did the volume of whitewood lumber produced. In all models, the variability in discolored and whitewood volumes caused model r^2 values to be low.

Erickson et al. (1992) reported similar trends of increases in the proportion of discolored wood (heartwood) area to cross-sectional area of the large end of sugar maple butt logs as log diameters increased in a Michigan study. They found that trees that were 12 in. in diameter on the large end of butt logs averaged 11% discolored wood based on the ratio of cross-sectional areas, whereas trees that were 25 in. in diameter averaged 26% discolored wood. In our study, we observed similar ratios for trees of comparable diameters, i.e., 14–20 in. dbh trees averaged 10% discolored wood (ratio of cross-sectional areas); trees that ranged from 20 to 25 in. dbh had 20% discolored wood. Others have noted that the size of discolored wood in sugar maple increases with increasing tree diameter (D'eon and Hamilton 2013, Havreljuk et al. 2013). In contrast, Yanai et al. (2009) found that the ratio of discolored wood diameter to the diameter of the small end of the butt log decreased with increasing log diameters in an extensive study of sugar maple in the northern United States. They also stated that there were no significant differences in discolored wood ratios among their 53 study sites and that there was high variation in discolored wood ratios with tree diameter. Germain et al. (2015) found that changes in the proportion of discolored wood were inconsistent with changes in diameter, and hence the relationship was insignificant in sugar maple in New York. It appears that absolute amounts of discolored wood increase with increasing tree diameter, but its proportion of tree diameter, cross-sectional area of log ends, or total log volume varies with increasing tree diameter with no apparent link to management history (Erickson et al. 1992) or geographic pattern (Yanai et al. 2009). We found that high proportions (>60%) of log volume can occur as discolored wood in trees that are 30 in. and greater dbh.

Total Tree Value

We found that 40% of tree value was in the first log, 25% was in the second log, and 17% in the third log. Value per tree was significantly related to tree dbh and age (Figure 4). Value increased with increasing dbh and decreasing age. Total value, at the time of the study, was highest for the largest diameter trees and, in particular, for those that were younger. Larger dbh grade 1 trees had veneer logs that occurred in the first three log positions. Larger dbh trees were usually older trees (Figure 1), but there was much variation in age among larger diameter trees (>30 in. dbh). Older trees displayed a trend toward decreasing proportion of volume in the higher valued whitewood grades, although the relationship was not significant (Table 3). It is a consistent observation that larger dbh trees have higher value but that the rate of increase in value is lower than for younger and small trees (Mendel et al. 1973, Smith et al. 1979). Old and large high-value trees are less likely to increase in grade, and rates of diameter growth are lower than those for young vigorous trees; therefore, they have lower rates of value increase. In addition, the longer trees live, the more likely they are to decline in grade and increase in proportion of discolored wood from agents and disturbances that cause injury to trees.

Discounted value was greatest for trees that were 100 years old, and it declined precipitously as tree age increased, approaching zero for trees that were older than 200 years (see Supplemental Figure S3). Increases in

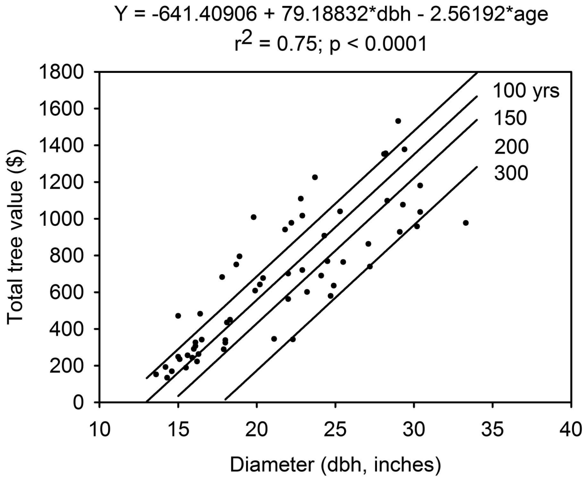

Figure 4. Total tree value by tree dbh and age. Value is the sum of revenue from veneer, lumber, cants, and bolts produced from each grade 1 sugar maple. Revenues from the sale of veneer are real based on competitive bids of the study logs. All other revenues are based on regional market averages at the time of manufacture of the products.

discounted value per tree occurred with increasing diameter in 100-year-old trees, but values were consistently low regardless of diameter for trees ≥200 years old. At the higher rates of diameter growth reported for sugar maple on high-quality sites in the Northern Region (Mendel et al. 1973, Crow et al. 1981, Leak et al. 2014), trees can grow to 22–26 in. dbh by age 100 to 140. Thus, it is possible to achieve tree diameters that we found were associated with high probability of veneer and grade sawlogs with high proportions of whitewood and hence high value in 100–150 years. Higher discount rates than used in this study would have the effect of shortening the time to and reducing tree diameter at financial maturity. Substantial increases in market prices than used in this study would have the opposite effect.

Leak et al. (2014) stated that sugar maple is mature at 100–140 years and mean annual volume growth levels off between 110 and 120 years, and high-vigor trees might attain a dbh around 26 in. if their growth potential is maximized on high-quality sites. We found that trees that were <25 in. dbh and <150 years old had high probabilities of having a veneer first log and higher proportions of whitewood. In contrast, large (>27 in. dbh), old (>150 years) sugar maple on the Menominee Reservation had low (<20%) probability of the first log being a veneer or grade 1 sawlog and a significant reduction in whitewood lumber. Although the absolute value was still high in old, large trees, the time it took to produce such trees substantially reduced their discounted value compared to that of smaller trees (<27 in. dbh) that were 100 years old.

Conclusions

The Menominee Tribe owns about 220,000 ac of forest lands that are dominated by sugar maple-northern hardwoods. The Menominee have developed forest management policies and practices that embody their strong land ethic, rich cultural values, ancient heritage, and commitment to future generations in a way that balances financial returns with tribal concern for biodiversity conservation, water quality, wildlife habitat quality, esthetics, and community stability. They understand that the forests are capable of providing many things for the people and that the health and productivity of the forest are intertwined with the wealth and spiritual well-being of the people. They place high regard on being good stewards of the land. Their approach to forest management demonstrates that economic return on forest products is not a mutually exclusive goal with a diversity of other social, cultural, and environmental goals.

Their holistic approach to forest management based on the premise that the people are part of the forest system ensures that future generations will benefit from a healthy and productive forest estate that continues to meet the needs of the people in a sustained way. The tangible result of their approach to forest management can be seen from space by astronauts and satellite cameras as their mature, older forests of larger diameter trees stand in stark contrast to the surrounding regional landscape that is dominated by agriculture, young forests managed for short-rotation fiber production, and high-graded hardwood forests.

We determined tree value of grade 1 sugar maple trees on the Menominee Reservation and related it to tree age and dbh to identify a target diameter and age that would produce high values at a reasonable discount rate while achieving the management goals of the Menominee people (MTE 2012). Grade 1 trees are the highest quality trees possible and represent what the potential is for developing value over time. We assessed trends in veneer and whitewood lumber production with tree dbh and age because they are the highest valued products that are likely to be produced and marketed in the northern region. We optimized the manufacture of logs from trees and lumber from logs to obtain the greatest value we could out of each tree, offering veneer logs by competitive bid and milling the rest as sawlogs at the Menominee mill in Neopit, Wisconsin.

We found that the first log, which contained 40% of the total tree value, had a high probability of being a veneer log, especially in trees <24 in. dbh. Log grade of first logs in larger trees began to decline, and they were more likely to have grade 2 or 3 sawlogs in the first position. Trees older than 200 years had low probabilities of having veneer in the first log. These results contributed to a decrease in tree value in larger, older trees, which, however, was compensated for by the increasing probability of veneer grades in second and third logs. The largest trees produced the highest value, but when value was discounted to account for tree age, we found that trees older than 100 years had greatly reduced value.

Our results confirm that the current Menominee silviculture prescription for uneven-aged management of sugar maple forests should position them well to recover high value from their forests while meeting other resource, cultural, and social objectives. The Menominee have successfully adopted the latest advances in forest science in a way that is compatible with their cultural worldview and in a way that blends well with their diverse goals for their forestlands. They have adopted the guidelines of Arbogast (1957) and have set maximum dbh at 20–24 in. This practice should yield high-value sugar maple. Stand management that maximizes growing large diameter sugar maple (i.e., 20–30 in. dbh) in 100–150 years, within the limits set by tree genetics and site productivity, will promote development of high-value trees and ensure that future generations will inherit a forest capable of meeting the varied needs of the people.

Endnote

1. For more information, see www.hmr.com.

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