Determinants of tree quality and lumber value in natural uneven-aged southern pine stands

Jeffrey P. Prestemon and Joseph Buongiorno

Abstract: An ordered-probit model was developed to predict tree grade from tree- and stand-level variables, some of which could be changed by management. Applied to uneven-aged mixed loblolly (*Pinus taeda* L.) – shortleaf pine (*Pinus* echinatu Mill.) stands, the model showed that the grade of pine trees was highly correlated with tree diameter, tree height, and stand basal area, in non-linear fashion. In addition, a tree was more likely to be of high quality if it grew on industry or government forestland, on poorer sites, and in stands that had been partially cut in the past. However, the effects of changes in these variables on the unit value of recovered lumber were small. The exceptions were tree diameter and height, which were the most important indicators of lumber value.

Résumé : Un modèle base sur l'ordination des probits a été développé dans le but de prédire la qualite des arbres à partir de variables descriptives du peuplement et de l'arbre. Certaines de ces variables pourraient être modifiées par l'amenagement. Lorsqu'on l'applique à des peuplements mixtes inéquiennes de pin à encens (*Pinus taeda* L.) et de pin jaune (*Pinus* echinatu Mill.), le modele montre que la qualitt des arbres est fortement corrélée, de façon non linéaire, au diamètre et à la hauteur des arbres ainsi qu'à la surface terrière du peuplement. De plus, la qualite d'un arbre a plus de chances d'être élevée s'il croît dans une forêt appartenant à l'industrie ou au gouvernement, sur des sites plus pauvres ou dans des peuplements qui ont déjà subi une coupe partielle. Cependant, les effets des changements dans ces variables sur la valeur unitaire du bois d'oeuvre transformé sont faibles. 11 y a deux exceptions : la hauteur et le diamètre de l'arbre qui sont les indicateurs les plus importants de la valeur du bois d'ceuvre.

[Traduit par la Redaction]

Introduction

The profitability of different management regimes depends in part on the quality of the logs they produce. In typical management models, log values are functions only of tree size (typically diameter), log grades being distributed in fixed proportions within each diameter class (for example, Reed et al. (1987); Clark et al. (1996)). However, recent research (Belli et al. 1993; Clark et al. 1994) shows that trees of a given size may have quite different grades and that this variability is due in part to stand characteristics such as density. Because a tree grade is based upon the grade of the log that it produces (Schroeder et al. 1968; Brisbin and Sonderman 1971; Hanks 1976; Reed et al. 1987), it follows that stand characteristics may affect tree and stand values. Because some stand characteristics, such as basal area, can be controlled by management, it is useful to know how they influence tree grade. This is especially true for uneven-aged stands, where we could find no tree quality relationships that have been described in the literature. Because uneven-aged management may be one way to address some of the concerns of some publics regarding the deleterious effects of even-aged management and harvesting methods, we believe it important to expand the knowledge base in this subject. With a better understanding of the intricacies and economics of this management approach, managers will be able to more optimally apply it. Finally, our interest in loblolly pine is motivated partly because of the prevalence of this timber type, which comprises 25% of land area and 64% of standing southern pine volume in the South (Powell et al. 1994), although uneven-aged stands are a small portion of these.

Received January 21, 1999. Accepted September 16, 1999.

J.P. Prestemon.[1] USDA Forest Service, Forestry Sciences Laboratory, P.O. Box 12254, Research Triangle Park, NC 27709, U.S.A. e-mail: jprestem/srs_rtp@fs.fed.us
J. Buongiorno. Forest Ecology and Management, University of Wisconsin at Madison, 1630 Linden Drive, Madison, WI 53706, U.S.A. e-mail:jbuongio@facstaff.wisc.edu

[1] Corresponding author.

The purpose of this study was to develop a model to predict the grades of standing trees from tree and stand characteristics for uneven-aged loblolly (*Pinus tueda* L.) – shortleaf pine (*Pinus echinatu* Mill.) stands in the southern United States. Understanding the roles of site, stand, and silvicultural practices in the production of value is important and has long been recognized. But the effects of these factors on value in uneven-aged stands are not well understood, particularly for southern pines. If uneven-aged management of southern pine is to become more widespread as a viable economic alternative to clear-cutting and other even-aged practices, then its effects on timber value need to be quantified.

We attempt to address this issue by analyzing the relationships between tree quality, as measured by tree grade, and tree and stand characteristics expected to influence quality. Our data are for trees growing in uneven-aged mixed loblolly-shortleaf pine stands in the South. While natural uneven-aged southern pine stands typically have hardwood trees that may be economically important, only southern pine stands classified by the Forest Service as loblolly or loblolly-shortleaf stands are examined in this paper. For these, the model predicted correctly the grades of 63% of the sample trees. In a validation data set, the model predicted

© 2000 NRC Canada

the proportion of trees in each grade to within 2% of the actual proportions. The model was employed to measure the contribution, in terms of dollars per cubic metre, of each statistically significant variable, thus identifying the factors that are most influential in the development of high-value trees in uneven-aged loblolly-shortleaf pine stands. These equations would allow the incorporation of tree grade in stand simulators (Schulte et al. 1997), enabling more precise predictions of the economic implications of alternative management strategies for this forest type.

After describing the methods, we present results of empirical estimation. The final equation is evaluated with alternative measures of good fit. Significant statistical relationships between tree grade and explanatory variables are revealed. The model is then applied to calculate marginal economic value of changes in each variable. Last, we discuss the implication of the findings for forest management modeling.

Methods

Standing sawtimber of all species in the eastern United States is graded in the periodic forest surveys conducted by the USDA Forest Service's Forest Inventory and Analysis (FIA) program, with the methods of Schroeder et al. (1968) for southern pine and Hanks (1976) for hardwoods. In Schroeder et al. (1968), southern pine tree grades were A (the best quality), B, and C (the worst), which the Forest Service has recoded numerically as 1, 2, and 3, respectively; we refer to the numerical codes in this paper. For southern pines, tree grades are based on the characteristics of the first 4.9 m log. For these species, the higher the number of clear faces in the first 4.9 m log, the better the tree quality, with deductions for dead and overgrown knots, other kinds of biological or mechanical damage, sweep, and crook. Tree grades are based upon the grades of lumber obtained after manufacture.

Tree grading rules guided development of the model to predict tree grades. In FIA surveys of stands relevant to this study, southern pine can be assigned any grade, 1 to 3, if the tree has a diameter at breast height (DBH) of at least 23 cm (9 in.) (Schroeder et al. 1968). Some trees are not graded in FIA surveys, including trees smaller than sawtimber sizes and others because of sample design. No standardized procedures exist for FIA assessment of quality of smaller-diameter trees, which had to be excluded. Still, the wood quality of these smaller-diameter trees would be worth future study.

There is little published work regarding the influences of stand and tree variables on southern pine tree grades, and only a few other studies have attempted to identify factors that affect stem quality for other species. One study, by Kärkkäinen and Uusvaara (1982), examined the factors affecting the quality of young Scots pine (*Pinus sylvestris* L.) in Finland. Tree quality was found to be positively related to tree DBH and to its deviation from the stand average DBH. Tree growth rate was also correlated with quality. Clark et al. (1994) found that the proportion of highest-quality logs was higher in stands with closer initial spacing and higher levels of stand densities after thinning. Belli et al. (1993) found that DBH (positively related to tree quality), basal area, stand age, and trees per acre explained grades of bottomland hardwoods in Mississippi.

The tree grading rules and past findings suggest that quality is a function of species, tree diameter, stand density, and site quality. Smith (1962) stated that branching and stem form are related to the degree of competition among trees, and species, diameter, density, and site quality, which influence that competition, should affect natural pruning. But competition may also translate as stress due to pathogenic and mechanical damage that a tree experiences in its lifetime (Smith 1962; Walker 1980). We might conclude, then, that the level of management (especially harvesting) practiced in a stand also influences tree quality.

To avoid statistical inconsistency due to the omission of relevant variables (Yatchew and Griliches 1985), all the tree and stand characteristics that could influence quality, and for which measures could be computed, were included in the original model. Thus, tree grade was expressed as

$$\text{Grade} = F[\text{DBH}, \text{BA}, \text{HT}, \text{SITE}, \text{LAT}, \text{LON}, \text{NIPF}, \text{CUT}] \tag{1}$$

where DBH is in centimetres; BA is basal area ($\text{m}^2 \cdot \text{ha}^{-1}$); HT is tree height (m); SITE is site productivity class (from low productivity, 6, to high productivity, 1); LAT is latitude (degrees north); LON is longitude (degrees west); NIPF = 1 if nonindustrial private ownership, 0 otherwise; and CUT is the proportion of basal area cut or killed by humans since the last survey. Size variables, especially height, were meant to account for the tendencies of trees to self-prune and produce clear logs as they get larger; stand basal area accounted for the influences of competition by other trees; site productivity class controlled for the influences of greater growth rates; geographic variables accounted for other environmental influences on quality (for example, precipitation, snow, ice, humidity, and extremes of temperature); and ownership and cutting accounted for human factors.

The dependent variable in [1] is discrete, and ordered. A tree is or is not of a particular grade, and grade 1 is superior to grade 2, which itself is superior to grade 3. This suggested an ordered probit model (Greene 1990, p. 703-706). The model involved a latent variable, y^*, related to explanatory variables in [1], x:

$$y^* = x'\beta + \varepsilon \tag{2}$$

and

$$\begin{cases} \text{grade} = 3, & \text{if } y^* < 0 \\ \text{grade} = 2, & \text{if } 0 \le y^* < \mu \\ \text{grade} = 1, & \text{if } y^* \ge \mu \end{cases} \tag{3}$$

The μ and β were estimated jointly by maximum likelihood. Assuming that ε was normally distributed across trees, grade probabilities (P) were calculated as follows:

$$\begin{cases} P(\text{grade} = 3) = \Phi(-x'\beta) \\ P(\text{grade} = 2) = \Phi(\mu - x'\beta) - \Phi(-x'\beta) \\ P(\text{grade} = 1) = 1 - \Phi(\mu - x'\beta) \end{cases} \tag{4}$$

© 2000 NRC Canada

where $\Phi(.)$ is the standard normal cumulative distribution function.

Once estimated, the ordered probit model can serve to predict the effects on tree grade probabilities of marginal changes in explanatory variables:

$$[5] \quad \begin{cases} \dfrac{dP(\text{grade} = 3)}{dx} = -\phi(x'\beta)\beta \\ \dfrac{dP(\text{grade} = 2)}{dx} = [\phi(-x'\beta) - \phi(\mu - x'\beta)]\beta \\ \dfrac{dP(\text{grade} = 1)}{dx} = \phi(\mu - x'\beta)\beta \end{cases}$$

where $\Phi(.)$ is the probability density function of the normal distribution.

The statistical significance of the variables used to predict grade was tested by the likelihood ratio statistic (Greene 1990, p. 393):

$$[6] \quad \mathrm{LRS} = -2(\ln L_0 - \ln L_\mathrm{m})$$

where L_m is the log-likelihood function of the estimated model and L_0 is the log-likelihood function of a model with only the intercept on the right-hand side. LRS is distributed as chi-squared, with degrees of freedom equal to the number of variables less one.

The model predictive power was also judged by the percentage of correct predictions, C_m:

$$[7] \quad C_\mathrm{m} = 100\frac{\sum C_i}{n},$$

and

$$C_i = 1, \quad \text{if } G(x_i) = \hat{G}(x_i)$$
$$C_i = 0, \quad \text{otherwise}$$

where $G(x_i)$ and $\hat{G}(x_i)$ indicate actual and predicted grades, respectively, given the values of the explanatory variables x_i for tree i in the sample of trees. The predicted grade was that of highest probability, as given by [4].

A shortcoming of C_m is that the highest probability method of predicting tree grade gives some correct predictions, no matter the model. Thus, C_m was also compared with the percentage of correct predictions from two "naïve" models. One, C_0, is the percentage of correct predictions obtained by assigning grades randomly to trees according to the grade frequencies in the sample:

$$[8] \quad C_0 = \frac{100}{n}\sum_{j=1}^{3} n_j\left(\frac{n_j}{n}\right)$$

where n_j is the number of trees of grade j. The other, Co, is the percentage of correct predictions obtained by assuming that all trees in the sample are of the most common grade:

$$[9] \quad C_\mathrm{D} = 100\frac{\max(n_1, n_2, n_3)}{n}$$

The improvement in predictive power given by the ordered probit relative to the naive models is

$$[10] \quad \mathrm{FII}, = 100\frac{(C_\mathrm{m} - C_0)}{C_0}$$

$$[11] \quad \mathrm{FII}, = 100\frac{(C_\mathrm{m} - C_\mathrm{D})}{C_\mathrm{D}}$$

Last, the model was judged in terms of its ability to predict the proportion of trees by grade in a postsample data set. Let $\hat{p}_{ij}(x_i)$ be the predicted probability that tree i is of grade j (obtained by [4]). The predicted proportion of trees of grade j in a postsample of size n is then

$$[12] \quad \hat{p}_j = \frac{\sum_i \hat{p}_{ij}(x_i)}{n}$$

Differences between the predicted proportion of grade j, $\hat{p}_j$, and the actual proportion of grade j, p_j, may reveal systematic bias.

Data

The data came from tree and plot records from the Central South region (Texas, Oklahoma, Tennessee, Arkansas, Mississippi, Louisiana), obtained during two consecutive FIA surveys (FIA's fifth and sixth inventories) conducted in the 1980s and 1990s. Because this study was part of a broader evaluation of uneven-aged management in loblolly-shortleaf pine ecosystems, trees were in stands that had at least two age-classes and that had not been regenerated artificially. The tree and stand data came from the second survey (i.e., the sixth inventory). That is, trees included in data for estimating tree grade equations were those that were alive at the time of the second survey. All trees that were graded and had complete data on all model variables were used. The final sample consisted of 9831 southern pine tree records and 991 plot records, the same plots from which the growth model of SouthPro was developed (Lin et al. 1998). Seventy percent of these observations, selected at random, made up the test sample for model development, and the rest for validation.

Summary statistics are in Table 1. The detailed grade distributions of the pines, soft hardwoods, and hard hardwoods are in Table 2. About 60% of the pines were of the lowest grade, the rest being distributed equally between grades 1 and 2. About 80% of the hardwood trees were of grade 2 or better. Little correlation was found between hardwood grade and stand condition, so the rest of the paper deals with pines only.

Results of grade model estimation

The parameters of the grade model were first estimated with squared terms for most variables, to account for possible nonlinearities in underlying relationships. To increase the efficiency of the parameter estimates and for simplicity, a parsimonious model was then created by keeping only parameters that were significantly different from zero at 10% significance. The residuals were assumed to be distributed heteroscedastically, with the variance specified to be an

© 2000 NRC Canada

Table 1. Summary statistics for southern pine trees and associated uneven-aged stands.

Variable	Units	Mean or mode	Minimum	Maximum	SD
Test data ($n = 6892$)					
Tree grade		3	1	3	
DBH	cm	38.4	22.9	87.4	10.7
Basal area	$m^2 \cdot ha^{-1}$	10.8	0.7	24.6	3.1
Site productivity class		3	1	6	
Tree height	m	25.1	1.8	45.7	4.9
Longitude	Degrees West	90.9	84.3	96.0	2.9
Latitude	Degrees North	32.1	30.0	36.3	1.1
NIPF dummy		0	0	1	
Basal area cut[a]	$m^2 \cdot m^{-2}$	0.03	0	1.0	0.07
Validation data ($n = 2939$)					
Tree grade		3	1	3	
DBH	cm	38.4	22.9	86.4	10.8
Basal area	$m^2 \cdot ha^{-1}$	10.7	2.2	23.2	3.1
Site productivity class		3	1	6	
Tree height	m	25.1	1.5	45.1	4.9
Longitude	Degrees	90.9	84.3	95.8	2.9
Latitude	Degrees	32.1	30.0	36.3	1.0
NIPF dummy		0	0	1	
Basal area cut[a]	$m^2 \cdot m^{-2}$	0.03	0.00	0.55	0.07

[a] Basal area cut or killed by humans between FIA surveys as a fraction of basal area at the time of the second survey.

Table 2. Grade distribution of trees growing in uneven-aged southern pine stands.

		Proportions in			
Species group	Sample size	Grade 1	Grade 2	Grade 3	Grades 4 and 5
Southern pine					
Test sample	6892	0.20	0.20	0.60	
Postsample	2939	0.20	0.18	0.62	
Soft hardwoods	496	0.23	0.57	0.15	0.05
Hard hardwoods	1041	0.30	0.48	0.15	0.07

exponentially linear function of the explanatory variables (Yatchew and Griliches 1985). The fully specified model and its parsimonious version are in Table 3.

Of the proposed variables, only geographic location by longitude and latitude did not seem to influence tree grade. The statistically significant squared terms (DBH, BA, and tree height) suggest that they influence tree grade in nonlinear fashion. Quality increased with the square of tree height, unambiguously increasing the probability that a tree was of grade 1. Lower site productivity was associated with higher probabilities of trees of grade 1, other things being equal. Trees in nonindustrial-private ownership had a lower probability of being grade 1 than those managed by public agencies and industry. The amount of previous cutting was positively related to the probability of a tree being of grade 1: cut stands may have undergone stand improvement measures in the past (not necessarily between the two inventories), so that, other things being equal, more of the remaining trees were of higher quality on the most intensely cut stands. The fraction of basal area cut, then, appears to be a proxy for management intensity.[2]

Statistical significance of both full and parsimonious specifications of the model were very good, as measured by log-likelihood test statistics (Table 4). For the final, parsimonious model, other goodness of fit measures, C_m, FII_0 and FII_D, were almost the same within and outside the sample, and there was no appearance of bias ($\hat{p}_i - p_i$). The model predicted correctly the grade of 63–65% of the trees (C_m). But, as shown in Table 3, most of those correct predictions were of grade 3 trees (95%); none of the grade 2 trees were predicted correctly, only about a quarter of the grade 1 trees were correctly predicted. The frequency of correct predictions was 18% higher with the model than by assigning grades randomly to trees based on the grade frequencies in

---

[2] A reviewer asked whether this was true for NIPF stands alone. This question was answered by interacting the CUT and CUT-squared variables with the NIPF variable. We found that the interactions were not statistically significant, indicating that NIPF stands were no different from other stands in the effect of contemporary cutting on quality.

Table 3. Ordered probit model parameters (A) and statistics (B) for the grade of southern pine trees.

(A) Model parameters

	Full specification		Parsimonious specification	
Variable	β	SE	β	SE
Constant	–3.9***	0.9	–3.4***	0.3
DBH	0.023***	0.009	0.03***	0.09
DBH^2	–0.0003***	0.0001	–0.0003***	0.0001
Basal area	0.04***	0.01	0.04***	0.01
(Basal area)*	–0.7***	0.2	–0.7***	0.2
Height	0.03	0.02		
$(Height)^2$	0.002***	0.000	0.002***	0.000
Site productivity class	0.2”	0.1	0.24***	0.02
$(Site\ productivity\ class)^2$	0.01	0.02		
Latitude	-0.01	0.02		
Longitude	0.01	0.06		
NIPF Dummy	–0.23***	0.03	–0.23***	0.03
Basal area cut	0.6	0.4	0.9***	0.2
$(Basal\ area\ cut)^2$	0.9	1.1		
μ	0.67***	0.02	0.67***	0.02

(B) Statistics

	Full specification	Parsimonious specification
Within sample statistics		
n	6892	6892
LRS	1123***	1118***
C_m		62.8
Grade 1 percent correct		27.0
Grade 2 percent correct		0.0
Grade 3 percent correct		95.1
FII_0		18.4
FII,		2.3
Postsample statistics		
n		2939
C_m		64.6
Grade 1 percent correct		26.2
Grade 2 percent correct		0.0
Grade 3 percent correct		95.0
FII,		18.5
FII,		2.1
$\hat{p}_1 - p_1$		-0.02
$\hat{p}_2 - p_2$		0.02
$\hat{p}_3 - p_3$		–0.00

Note: Asterisks show coefficients significantly different from zero at the 10% (*) and 1% (***) level, respectively.

© 2000 NRC Canada

Table 4. Raw lumber percentage distribution by tree grade for a 40.6 cm DBH, two (4.9 m)-log loblolly pine tree, and wood value unit value of the resulting kiln-dried lumber.

	Tree grade[a]		
Lumber grade	1	2	3
B&B, C	19	11	6
D&1C	16	16	12
2C	21	27	29
3C	5	4	4
4C	1	1	0
1D	13	18	13
2D	18	17	22
3D	6	6	14
4D	1	0	0
Lumber value ($/m^3)[b]	294	282	261

[a] Schroeder et al. (1968, p. 9).

[b] Gross of processing cost, based on lumber prices from *Random lengths* (Random Lengths Publications 1997) and lumber grade translations in Table 5. The metric conversion factor for lumber was 1000 board feet (bf) = 2.36 m^3.

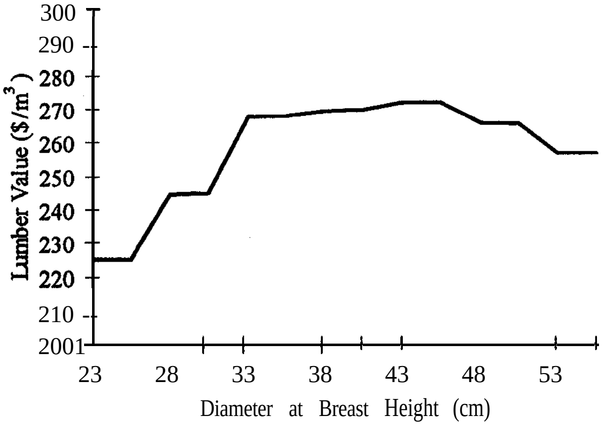
the sample (FII_0). But it was only 2% higher than by simply assigning to all trees the most frequent grade in the sample (FII_D).

Converting tree grades to values

One way to use the model is to predict the marginal effects of explanatory variables on probabilities that trees would be of different grades ([5]). But tree grading is done for industrial reasons, and it has economic implications. It seems, therefore, more informative to predict the effects of changes in variables such as tree height and stand density on the unit value of the recovered lumber.

Schroeder et al. (1968) estimated the grade distributions of southern pine lumber obtainable from each tree grade by number of logs. That is, they developed equations for varying merchantable heights by diameter, given the grade assigned by evaluating the characteristics of the butt log and whether or not heartrot is evident anywhere on the merchantable portion of the stem. Thus, for a grade A (FIA grade 1), two-log loblolly pine with a DBH of 41 cm, they estimate the following lumber quality distribution: 12% of the volume in B&B, 7% in C, 16% in D&1C, 21% in 2C, etc. (Table 4). For the research reported here, B&B and C lumber grades were combined into a grouping called “C and better,” and others were assigned according to today’s frequently reported lumber grades. It should be kept in mind that these estimates represent technology and production standards of the 1960s. Schroeder et al. (1968, p. 5) stated that their equations were based on Southwide averages and that, therefore, the actual mix obtained in a particular mill would vary. Nonetheless, we believe that their equations are still useful for general comparisons of tree grades. Prices for calculating the value of lumber in each tree came from ***Random Lengths*** (Random Lengths Publications 1997, pp. 5–8), adjusted for log size (Table 5). The value per unit of volume of a tree of characteristics x is therefore:

Fig. 1. Effect of tree diameter on value of recovered lumber in uneven-aged loblolly pine stands in the Central South.



$$[13] \quad V(x) = \sum_{j=1}^{3} p_j(x) \sum_{q=1}^{9} P_q r_{jq}$$

where p_j is the probability that the tree is of grade j, P_q is the price of the qth lumber grade, and r_{jq} is the proportion of a tree of grade j that produces the lumber of grade q. Assuming similar manufacturing cost for trees of differing grade, the economic effect of changing the kth characteristic, x_k, other things being equal, was evaluated at the mean of x and obtained from [13].[3]

Results of economic significance evaluation

Table 6 reports the effects on the unit value of the recovered lumber of small changes of each statistically significant explanatory variable from its sample mean or mode. These effects were computed for southern pine trees with two merchantable logs and the sample average DBH, which happens to be close to a typical harvested southern pine tree in the South. The mean and modal values are shown in Table 1.

Marginal changes in tree and stand characteristics had apparently small effects on the value (in dollars per cubic metre) of the resulting potential lumber. A more complete picture of the effect of the important managerial characteristics on tree value, taking into account the nonlinearities, is given in Figs. 1 to 5. Here, each characteristic spans the entire range observed in the sample (except for tree DBH, limited to the range used by Schroeder et al. (1968)). The figures show the partial effect of one variable on expected unit value of the recovered lumber when all others were held constant at their sample mean or mode.

Figure 1 plots the expected wood value per cubic meter of lumber obtained. It therefore excludes the higher volume recovery in sawing larger diameter logs. Value per cubic meter

---

[3] A limitation of the “lumber method” of valuation is that it assumes trees become lumber only. Today, opportunities exist for marketing stumpage for higher value products. As an alternative to the lumber valuation method, we also analyzed the economic effects of explanatory variables by assuming that grade 1 trees were suitable for utility poles and grade 2 and 3 trees were suitable for sawtimber. This valuation method yielded results similar to those shown for the lumber valuation approach.

Table 5. Southern pine kiln-dried lumber prices by grade and log size ($/m^3).

Schroeder et al.'s (1968) grade	Random lengths Grade	Random lengths Product	Diameter of log (in. or cm) 10 25.4	12 30.5	14 35.6	16 40.6	18 45.7	20 50.8
B&B, C	C & better	Boards	449	449	449	449	466	466
D&1C	D	Boards	364	364	381	381	381	381
2c	No. 2	Boards	256	256	292	292	292	292
3c	No. 3	Boards	157	157	159	159	172	172
4c	Economy or No. 4	Boards, random	93	93	93	93	93	93
1D	No. 1	Framing, 16"	210	210	218	218	231	231
2D	No. 2	Framing, 16"	197	197	214	214	220	220
3D	No. 3	Random, framing	153	id.	id.	id.	id.	id.
4D	Utility or No. 4	Random, framing	153	id.	id.	id.	id.	id.

Note: Metric conversions are as follows: 1 in. = 2.54 cm; 1ft = 0.3939 m; 1000 bf of lumber = 2.36 m^3. Price data from *Random lengths*, June 6, 1997, issue (Random Lengths Publications 1997) for the Central South region. The variations in price of framing lumber by log diameter were estimated by assuming that 10 and 12-in. DBH trees would produce 1 in. x 6 in. lumber; 14- and 16-in. DBH, 1 in. x 8 in. lumber; and 18- and 20-in. DBH, 1 in. x 10 in. lumber. Prices for larger width trees are held constant at smaller width lumber prices if larger width lumber prices are lower than the smaller width product.

"The upper values in the box head are inches, and the lower values are centimetres.

Table 6. Effects of changing statistically significant tree and stand variables on southern pine lumber value.

Explanatory variable	Change from mean or mode	Lumber value change ($/m^3)
DBH	+5 cm	0.03
Basal area	$+1\ \mathrm{m^2 \cdot ha^{-1}}$	0.02
Tree height	+1 m	1.10
Site productivity class	+1	2.63
NIPF ownership dummy	-1	2.54
Basal area reduction	+0.10	0.98

Fig. 2. Effect of stand basal area on value of recovered lumber in uneven-aged loblolly pine stands in the Central South.

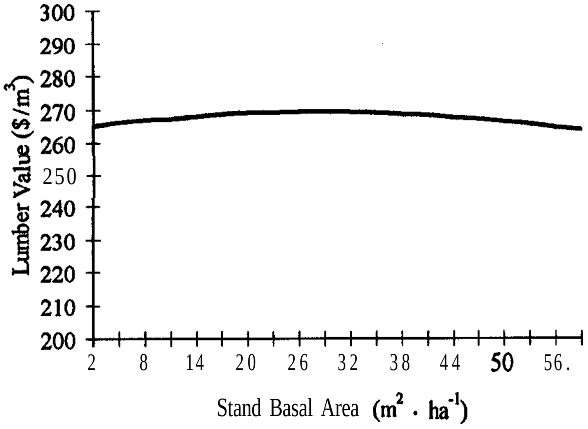
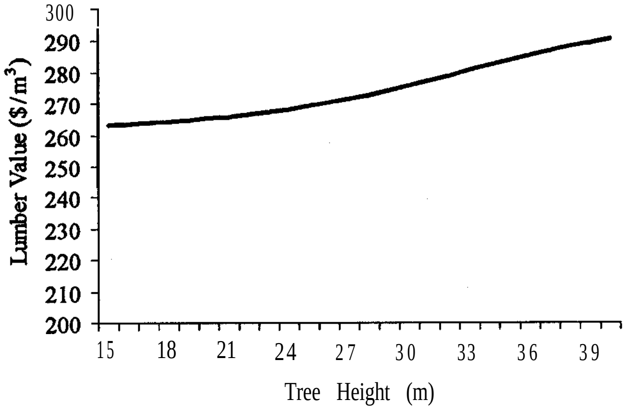


Fig. 3. Effect of tree height on value of recovered lumber in uneven-aged loblolly pine stands in the Central South.



of lumber increased with DBH, beginning at about 25 cm. This increase is attributable to (i) the increase in the proportion of higher quality lumber grades obtainable from higher quality trees (see Table 4), and (ii) the increase in price per cubic meter of obtained through cutting wider-dimension lumber (see Table 5). Value leveled-off at 36 cm and then declined from 46 cm (Fig. 1). The decline in expected value for stems over 46 cm is due to declining expected tree quality, probably because of the increased chances of finding mechanical and pest damage on larger (and possibly older) trees. Although the marginal value of a change in DBH from the sample average DBH, was only a few cents per cubic meter (Table 6), the variation from 25 to 45 cm was substantial, about $40/m^3.

Stand basal area (Fig. 2) had only a small effect on the unit value of recovered lumber, despite its highly statistically significant effect on tree quality. Expected lumber value peaked at a stand density of about 30 $\mathrm{m^2 \cdot ha^{-1}}$. But the curve is slightly inverse-u-shaped; stands with very low and very high densities produce lumber with the lowest value per cubic metre. The small effect of basal area is highlighted by the result, shown in Table 6, that the marginal effect of basal area at the mean was only a few cents per square metre per hectare.

Tree height instead had a positive effect on the price of the recovered lumber (Fig. 3). There was a peak in marginal price around 35 m, where an additional meter of height added $2/m^3 of lumber obtained (Table 6). The price increased throughout the range of tree height represented in the data for the average-diameter tree, though the rate of increase in value declined with heights above 30 m.

© 2000 NRC Canada

Fig. 4. Effect of site productivity class (where higher site productivity class numbers are of lower productivity) on value of recovered lumber in uneven-aged loblolly pine stands in the Central South.

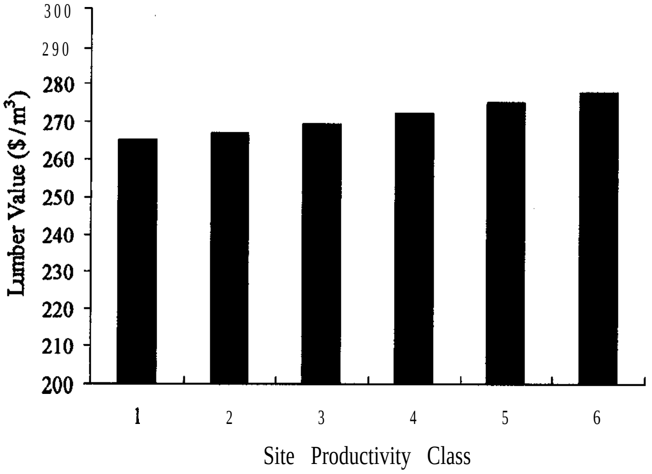


Fig. 5. Effect of reducing basal area through cutting or killing on value of recovered lumber in uneven-aged loblolly pine stands in the Central South.

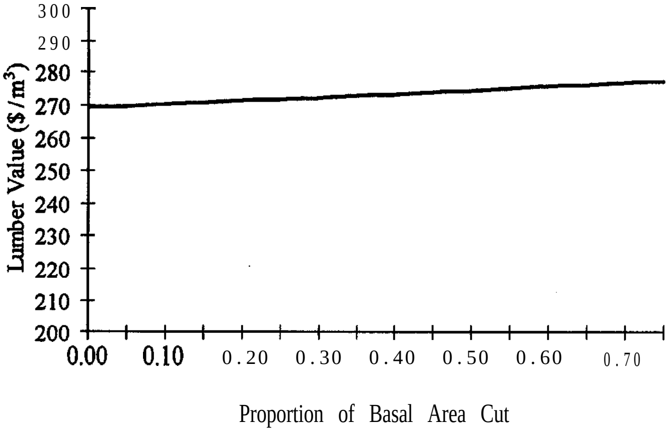


Figure 4 shows that trees were most valuable on the least productive lands. Overall, a tree growing on site class 2 would be worth \$12/m^3 less than one growing on site class 5, other things equal. A possible explanation for this modest effect is that trees on lower sites grew more slowly. Slower growth implies that trees on these sites are older, possibly meaning that they have had more time to self-prune, occlude branch scars, and develop a clear log by the time they reach sawtimber size. A one-unit reduction in site productivity class (from 3 to 2) was estimated to result in a \$2.6/m^3 increase in expected value per unit of lumber.

Trees growing on NIPF lands were of lower value, other things equal, than those growing on non-NIPF lands (Table 6). The marginal effect of NIPF ownership is about -\$2.5/m^3 of lumber obtained.

Although trees in heavily cut stands were of significantly higher quality (Table 3), the effect on the price of the recovered lumber over the range of observations was small (Fig. 5). The slight positive relationship found implies that the more intensely harvested stands tended to have better trees, possibly due to past stand improvement measures. On average, a \$1/m^3 higher wood value (of lumber produced) was associated with a 10% higher fraction of basal area cut.

One potential use of these results is to identify stands where conditions are favorable for producing valuable lumber. For example, a typical tree (sample average DBH and height) growing in a stand of modest density (29 m^2·ha^{-1} basal area) with low site quality (site productivity class 5) under non-NIPF ownership had an expected wood value in lumber of \$278/m^3. The same size tree growing in a high-density stand (59 m^2·ha^{-1} basal area) with high site quality (class 2) under NIPF ownership has an expected wood value in lumber of \$263/m^3. Though modest per unit, this difference would add up to large amounts over wide forest areas.

Summary and conclusions

Tree quality of southern pine in loblolly pine stands was found to be related to several tree and stand characteristics. The smallest and largest diameter trees had lower quality and wood value, with wood value peaking between 36 and 46 cm DBH. Quality was significantly better, statistically, in moderately dense stands (20-40 m^2·ha^{-1} basal area), but the economic effect of varying stand density was small. The most important determinants of wood value (i.e., the price of the recovered lumber) through quality improvement were tree diameter and tree height. Lower productivity sites tended to carry trees of higher quality, other things being equal, but the effect was small and may be largely compensated by the fact that trees grow taller on better sites. Private nonindustrial ownerships had worse quality trees, other things being equal, lending support to a contention that NIPF lands have a history of high grading that has left trees of worse form (Bridgwater 1984). Last, stands that had been cut more tended to have higher quality trees left, suggesting a selective, value-enhancing, silviculture and other stand-improvement measures. The economic effects of such past measures on value, however, had been modest.

There are plausible causal explanations for the results obtained for most variables, based on silvicultural knowledge (Smith 1961, 1962). This suggests that forest owners can influence the value of wood through practices that affect tree quality. Lumber value was highest in the tallest trees of 30-40 cm in diameter. Although stand density per se did not have a large effect on lumber value, there is a significant positive effect of stand density on tree height, and a negative effect on tree growth (Lin et al. 1998). Therefore, silvicultural manipulation of basal area may indeed matter in managing for tree quality, but in a complex way.

While the estimated tree grade equations had low explanatory power, they nevertheless suggest statistically and economically important stand characteristics that influence tree grade. Ultimately, the full impact of these characteristics could be revealed by incorporating the quality equations developed here in the SouthPro simulator (Schulte et al. 1997), which uses the density-dependent tree growth and tree height equations of Lin et al. (1998). This could eventually lead to the design of optimum strategies to maximize timber income from uneven-aged management of the South's most economically important timber species, by considering both the volume of trees and the quality of their wood.

© 2000 NRC Canada

Acknowledegements

The research was supported by the USDA Forest Products Laboratory's Wood Utilization for Ecosystems Management Project, the USDA Forest Service's Southern Research Station, McIntire-Stennis grant No. D946, and the School of Natural Resources at the University of Wisconsin, Madison. We thank Ching-Rong Lin, Ken Skog, John Pye, Joseph Denig, Lawrence Jahn, Alex Clark, Alan Long, Robert Bailey, and David Wear for their support and collaboration.

References

Belli, K.L., Matney, T.G., Hodges, J.D., Deen, R.T., and Goelz, J.C.G. 1993. Tree grade prediction for Mississippi bottomland hardwoods using discriminant analysis. South. J. Appl. For. 17: 120-123.

Bridgwater, F.E. 1984. The impact of genetic improvement of stem straightness on yield and value of lumber. *In* Proceedings of the Symposium on Utilization of the Changing Wood Resource in the Southern U.S., 12-13 June 1984, Raleigh, N.C. North Carolina State University, North Carolina Agricultural Extension Service, Forest Products Research Society, Raleigh, and the Society of American Foresters, Bethesda, Md. pp. 80-87.

Brisbin, R.L., and Sonderman, D.L. 1971. Tree grades for eastern white pine. USDA For. Serv. Res. Pap. NE-214.

Clark, A., III, Saucier, J.R., Baldwin, V.C., and Bower, D.R. 1994. Effect of initial spacing and thinning on lumber grade, yield, and strength of loblolly pine. For. Prod. J. 44: 14-20.

Clark, A., III, McAlister, R.H., Saucier, J.R., and Reitter, K. 1996. Effect of rotation age on lumber grade, yield, and strength of unthinned loblolly pine. For. Prod. J. 46: 63-68.

Greene, W.H. 1990. Econometric analysis. Macmillian Publishing Co., New York.

Hanks, L.F. 1976. Hardwood tree grades for factory lumber. USDA For. Serv. Res. Pap. No. NE-333.

Kärkkäinen, M., and Uusvaara, 0. 1982. Nuorten mlntyjen laatuun vaikuttavia tekijöitä. [Factors affecting the quality of young pines.] Folia For. 515: 2-27.

Lin, C.R., Buongiorno, J., Prestemon, J., and Skog, K. 1998. A growth model for uneven-aged loblolly pine stands, with simulations and management implications. USDA For. Serv. Res. Pap. No. RP-569.

Powell, D.S., Faulkner, J.L., Darr, D.R., Zhu, Z., and MacCleery, D.W. 1994. Forest resources of the United States, 1992. USDA For. Serv. Gen. Tech. Rep. No. RM-234.

Random Lengths Publications. 1997. Random lengths. Random Lengths Publications, Eugene, Oreg. Vol. 53. Issue 23.

Reed, D.D., Lyon, G.W., and Jones, E.A. 1987. A method for estimating log grade distribution in sugar maple stands. For. Sci. 33: 565-569.

Schroeder, J.G., Campbell, R.A., and Rodenbach, R.C. 1968. Southern pine tree grades for yard and structural lumber. USDA For. Serv. Res. Pap. SE-40.

Schulte, B., Buongiorno, J., Lin, C.R., and Skog, K. 1997. SouthPro: a computer program for uneven-aged management of loblolly pine stands. Department of Forest Ecology and Management, University of Wisconsin, Madison.

Smith, D.M. 1961. Comments on "Relationship between tree spacing, knot size, and log quality in young Douglas-fir stands." J. For. 59: 682-683.

Smith, D.M. 1962. The practice of silviculture. John Wiley & Sons, New York.

Walker, L. 1980. The Southern Pine region. *In* Regional silviculture of the United States. *Edited* by J.W. Barrett. John Wiley & Sons, New York. pp. 231-276.

Yatchew, A., and Griliches, Z. 1985. Specification error in probit models. Rev. Econ. Stat. 67: 134-139.

© 2000 NRC Canada