Modeling wood properties of planted Loblolly pine from pith to bark and stump to tip

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ABSTRACT

Variation in wood properties follows identifiable patterns within individual trees of Loblolly pine (*Pinus taeda* L.). Wood properties were sampled from disks cut at 1.52 m intervals from 131 mature trees across the natural range of the species. Wood property and mensurational data were used to develop predictive models describing the distribution of key wood properties in three dimensions. Patterns of wood density are described ring-by-ring from the pith to bark and vertically from stump to tip using mathematical models derived from wood sheath increment. A three parameter Logistic function describes the sigmoid curve of latewood specific gravity from pith to bark. By making the Logistic parameters functions of height, a three-dimensional model was developed which describes the changes in latewood specific gravity within the tree. Identifying and predicting properties of the juvenile core and the transition to mature wood are examined. The availability of such models can lead to improved merchandizing decisions for trees and logs and to improved wood quality estimates from forest inventories.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is the most important commercial species in the U.S. South. This region produces 58 percent of the marketed timber in the United States and 16 percent of all timber marketed in the world (Wear and Greis, 2002). Loblolly pine is the primary species of the U.S. pulp and paper industry and is also a desired resource for use in the manufacture of lumber and composite wood products. Among the many wood properties important to these manufacturing processes and uses, wood density stands out as the single most important measure due to its high correlation with pulp yield and solid wood strength properties. Specific gravity for Loblolly pine varies with growing conditions, management practices, and genetics (Larson *et al.*, 2001 ; Clark and Daniels, 2003). Wood SG increases significantly with age. Younger trees contain a large proportion of juvenile wood. Juvenile wood differs from mature wood in that it has a lower SG, lower percentage of latewood, and shorter tracheids with larger microfibril angles (MFA ; Larson *et al.*, 2001).

Within individual trees, specific gravity and other properties, such as MFA and stiffness, have been observed to vary in predictable patterns from stump to tip and from the pith to the bark (Evans *et al.*, 2000). Quantifying these patterns with mathematical models provides a means to predict wood performance properties within trees and logs, extending and generalizing our knowledge to aid in forest management, wood procurement, and wood utilization decisions. Tasissa and Burkhart (1997) modeled ring specific gravity as a function of physiological age, ring width and latewood proportion using linear models. The same authors (Tasissa and Burkhart, 1998) used linear segmented models to demarcate juvenile-mature wood transition. Phillips (2002) used non-linear functions to model the changes in cross-sectional specific gravity and moisture content of Loblolly pine as a function of height from stump to tip. In each of the modeling examples the authors noted the importance of identifying the tree effect in the model fitting procedure, either by use of mixed-effects models or stochastic parameter estimation.

Models capable of predicting specific gravity and other important properties anywhere within the tree could greatly improve quality predictions and utilization performance. With the ability to predict wood properties such as specific gravity at any point within the stem the Southern pine wood industry could better optimize the merchandising of tree stems for the most appropriate product. In addition, such models would allow growers to forecast the proportion of future stand yields by product class. Such information would contribute to the differentiation of wood markets based on wood quality.

The objective of this research was to develop and demonstrate a three-dimensional model for predicting SG of Loblolly pine by ring, from pith to bark, for any height, from the stump to the tip.

The SG data were assembled in a common dataset and plotted to identify patterns by height and ring (physiological age). Earlywood SG was found to be nearly constant across rings (Fig. 2A). Earlywood SG did not vary by height. Latewood SG followed a typical sigmoid pattern increasing from the pith through a transition period toward an upper asymptote (Fig. 2B). Similar patterns were found at all height levels, with the apparent maximum SG decreasing with height. Because the variability lies in the latewood specific gravity it was decided to model latewood SG as a function of rings from pith and height.

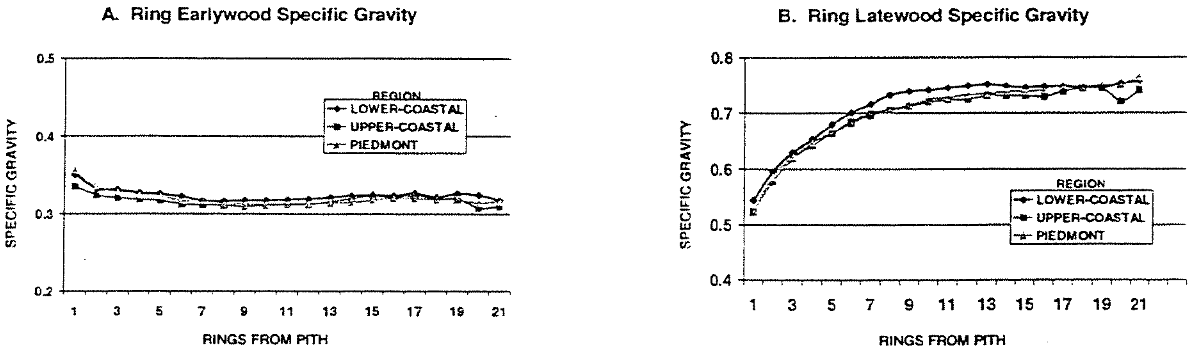

Figure 2 : Variation in A) earlywood and B) latewood specific gravity at breast height by rings from pith.

By plotting higher wood densities with lighter shades (Visual Numerics, 2000), Figure 3 depicts the overall variation patterns in latewood SG by ring and by height for all 131 trees. Note that the juvenile core is readily identifiable in the first few rings at all height levels. The transition wood is easily identified after ring 3, leading to denser wood at older physiological ages at all heights. A band of very dense wood is apparent in the lowest several meters.

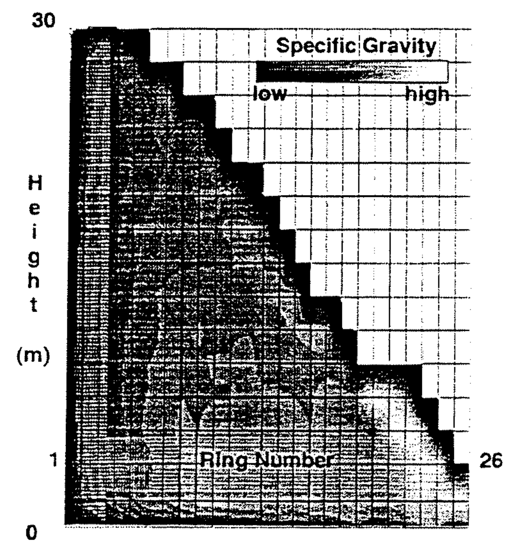

Figure 3 : Patterns of radial and longitudinal variation in latewood density for 131 loblolly pine trees.

A three-parameter Logistic model was selected from among several candidate models to describe the sigmoid pattern of variation in latewood SG from pith to bark (Fig. 2A). The three-parameter Logistic function can be written as :

$$f(x) = \frac{\phi_1}{1 + \exp[(\phi_2 - x)/\phi_3]}$$

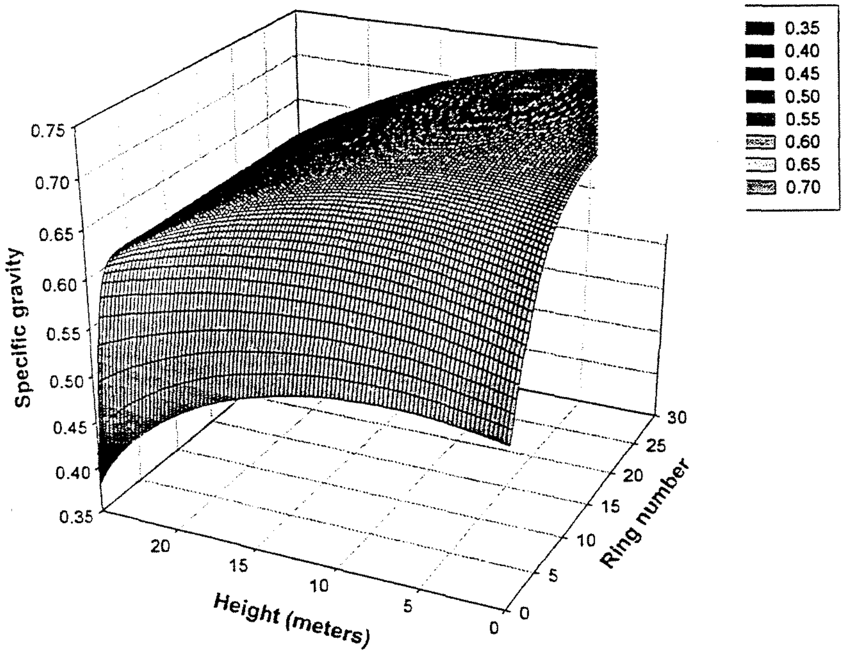

Figure 4 : Three dimensional plot of fitted Logistic equation for Loblolly pine latewood SG as a function of ring number and height.

Table 2 : Fit statistics for 3-D Logistic model for Loblolly pine latewood specific gravity.

Coefficients	Value	Std Error	t-value	p-value
b_{01}	0.7273	0.00285	55.52	<.0001
b_{11}	0.0004	0.00021	1.83	0.0665
b_{21}	0.0000	0.00000	- 6.51	<.0001
b_{02}	-2.8934	0.12794	-22.62	<.0001
b_{12}	0.0119	0.00551	2.17	0.0303
b_{22}	0.0002	0.00007	3.22	0.0013
b_{03}	3.1210	0.09053	34.47	<.0001
b_{13}	-0.0299	0.00261	11.47	<.0001

Standardized Residuals :

Min	Q1	Med	Q3	Max
-4.3143	-0.64917	0.044971	0.71624	3.6527

Overall Fit Statistics :

AIC : -60606 BIC : -60513 Log-Likelihood : 30315

Degrees of freedom : 16909 total ; 16901 residual

Residual standard error : 0.06215

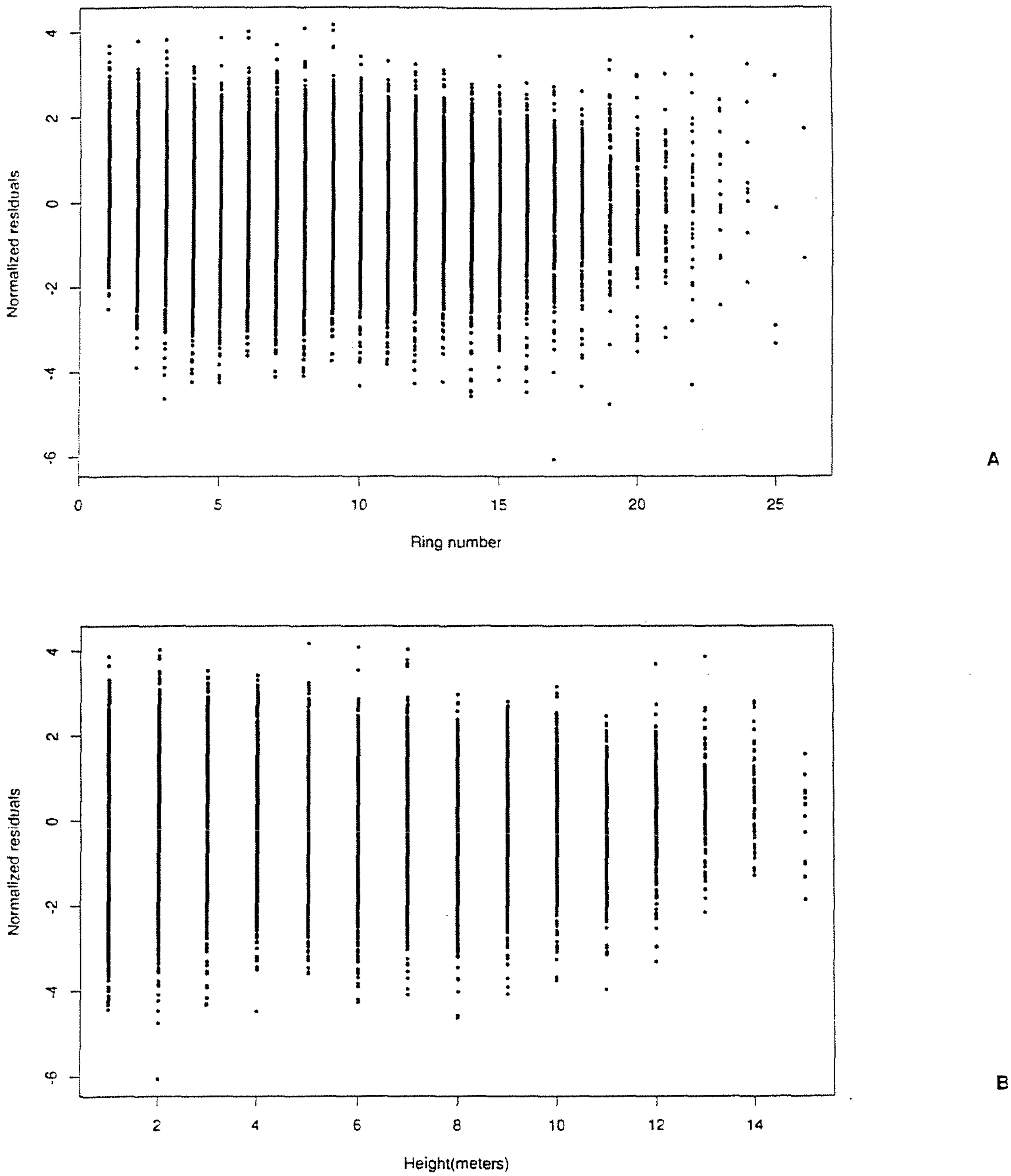

Figure 7 : Plot of normalized residuals versus A) *ring number* B) *height* from fitted 3-D Logistic model for latewood SG of Loblolly pine.

CONCLUSIONS

By examining variability of specific gravity within loblolly pine trees patterns can be identified by ring, from the pith to the bark, and by height, from the stump to the tip. These patterns follow logical, predictable trends. By identifying the shapes of these trends and choosing appropriate mathematical functions that match these shapes, we identified candidate models for describing specific gravity in three dimensions. The Logistic function was modified to explain a changing sigmoid relationship in three dimensions. This 3-D Logistic model described the major trends in latewood specific gravity, with two exceptions. The function under-predicted a band of dense wood near the bark within the first log and it over-predicted a trend for lower SG at the stump.

Overall these results show promise for a family of wood property models that will improve predictions of wood quality trends within loblolly pine trees and logs. Such models would help in optimizing the merchandizing of wood products. Growers could use these models with growth and yield projections and do a better job of incorporating wood quality considerations into forest management planning and harvest scheduling. At the time of harvest this