WITHIN-TREE VARIABILITY IN WOOD QUALITY PARAMETERS FOR MATURE LONGLEAF PINE

Chi-Leung So, Thomas L. Eberhardt, and Daniel J. Leduc

Abstract—Mature longleaf pine (*Pinus palustris* Mill.) trees were harvested from a spacing, thinning, and pruning study on the Palustris Experimental Forest, LA, to assess wood quality parameters of earlywood specific gravity (SG), latewood SG, ring SG, and latewood percent using X-ray densitometry. For each of ten 70-year-old trees used in the study, 2-inch thick disks were cut every 2 feet from the stump cut at 0.5 feet. A strip of wood was cut from bark to bark, and through the pith, to afford "cores" from bark to pith for the northern and southern cardinal directions. This sampling scheme provided the opportunity to compare wood properties determined at breast height to whole-tree area-weighted values. Only a few effects of silvicultural treatment were significant. As expected for spacing, an increase in ring width appeared to accompany wider planting densities. Significant differences were observed in whole-tree values as compared with those at breast height alone, in particular with north-south differences related to ring and latewood SG.

INTRODUCTION

The southern pine forest was predominated by longleaf pine (*Pinus palustris* Mill.) prior to colonial settlement of the United States. Through fire suppression activities and natural seeding on abandoned agricultural lands, the occurrence of loblolly pine (*Pinus taeda* L.) increased (Fox and others 2007, Stanturf and others 2002). Widespread planting further changed the landscape to where now more than half of the volume of southern pine timber is loblolly pine (Shiver and others 2000). Studies on the productivity, variability, and utilization of the southern pines have therefore focused primarily on loblolly pine. However, as efforts to restore longleaf pine ecosystems continue, it is anticipated that longleaf pine timber will be sufficiently available for utilization (Landers and others 1995), thus, warranting assessments of physical and mechanical properties of the currently available longleaf pine merchantable timber.

Prior to a timber sale from a spacing, thinning, and pruning study site on the Palustris Experimental Forest, longleaf pine trees were made available for destructive sampling. Preliminary results provided tree property maps of predicted SG values for a few individual trees (So and others 2010); this was accomplished via multivariate analysis of near infrared spectroscopy data collected by scanning pith to bark wood specimens. Additional measurements were performed on the study trees to determine inner and outer bark thicknesses along the length of the bole (Eberhardt 2013, 2015). Measurements of bark thicknesses were conducted to provide data for each of the cardinal directions (north, south, etc.). Results of paired t-tests showed statistically-significant differences in bark thickness measurements for the northern and southern quadrants, but not for the eastern and western quadrants (Eberhardt 2013). Given the appearance of limited north vs. south SG asymmetries in the aforementioned individual tree property maps (So and others 2010), the present study was conducted to determine if significant differences could be determined by the direct determination of SG by X-ray densitometry.

MATERIALS AND METHODS

Ten 70-year-old longleaf pine trees were harvested. The study site was located on the Palustris Experimental Forest, LA (N31.176°, W92.677°). Trees were sampled across the different silvicultural treatments (spacing, thinning, and pruning), affording a range of diameters at breast height from 5.7 to 19.6 inches (table 1). Total heights varied from 57.7 to 90.3 feet. Reviewing the treatments, spacing was at four levels (4.3, 5.2, 6.2, 13.1 feet), thinning was to a variety of basal areas (e.g., 100 square feet per acre), and trees were either pruned or left unpruned.

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Table 1—General characteristics of 70-year-old longleaf pine trees used in study

Tree Number	Diameter at Breast Height	Height	Height to Live Crown	Diameter at Live Crown	Basal Area	Spacing	Pruning
	(inches)	*(feet)*	*(feet)*	*(inches)*	*(feet^2/acre)*	*(feet × feet)*	
1	19.6	83.6	38.8	16.1	100	6.2	unpruned
2	13.0	89.5	58.7	6.8	186	6.2	pruned
4	14.5	86.4	50.5	9.3	100	5.2	unpruned
7	5.7	57.7	46.0	2.3	162	4.3	pruned
8	16.8	87.4	48.5	12.1	142	13.1	pruned
9	16.6	86.4	60.3	8.7	96	5.2	unpruned
11	10.3	90.3	65.7	5.2	151	5.2	pruned
12	13.7	75.0	42.9	8.2	151	5.2	pruned
13	13.4	83.2	50.7	10.7	112	6.2	pruned
17	11.3	85.8	64.8	5.0	158	5.2	pruned

Although the treatments for the harvested trees were known (table 1), it was well beyond the scope of the current study to make any definitive assessments of treatment effects on tree growth and wood quality parameters due to the limited number of trees subjected to destructive sampling. That stated, ANOVAs were generated simply to observe any trends in the wood quality parameters, classifying the data by spacing and pruning. The thinning data were also classified, using current basal areas (<111, 111-155, >155 square feet per acre), with these criteria affording a minimum of three trees in each basal area class.

Prior to felling, the trees were marked to identify the northern cardinal direction. Trees were felled, de-limbed, marked again, and then bucked with a chainsaw to produce 2-inch thick disks cut at a height of 0.5 feet and then every 2 feet along the bole, including at breast height. The northern cardinal direction was again marked on the top of each disk, after which a 0.5-inch thick wood slice was sectioned along the north-south direction, through the center of each disk, encompassing the pith. The wood slices were then extracted by steeping in acetone at room temperature over a 2-week period, with the solvent exchanged every 2nd or 3rd day. Wood slices were placed in wooden core holders, dried (50 °C, 24 hours), and then permanently glued into place. Mounted specimens were sawn into 2.3-mm thick strips, from bark to pith, leaving the transverse surface of the core exposed and bordered by adhering wood strips remaining from the core holders. Densitometry was employed to collect wood quality parameters (e.g., ring SG, latewood percent) and ring widths; this was performed using a Quintek Measurement Systems (Knoxville, TN) X-ray densitometer as described in Eberhardt and Samuelson (2015). Briefly, SG measurements were determined at 0.06-mm intervals, scanning along the radial direction from bark to pith. A SG of 0.480 was used to differentiate between earlywood and latewood zones (Antony and others, 2012; Clark and others, 2006; Koubaa and others, 2002).

Wood quality parameters were collected from the 'whole tree' (all disks), as well as from the breast height disk alone for each tree. These parameters were weighted by ring area to obtain mean area-weighted whole-core values for each tree, both at breast height, and to determine whole-tree values, further weighting the data by the transverse area of each disk. The effects of spacing, pruning, and basal area class on wood quality data were tested by analysis of variance (ANOVA) using SAS (SAS 2004), while the effect of cardinal direction was tested by a paired t-test using SAS (SAS 2004), both with significance at a P <0.05 level.

RESULTS AND DISCUSSION

The effects of thinning and pruning treatments on the wood quality parameters are shown in table 2 for the breast height and whole-tree values. Significant differences (P <0.05) were not observed for the breast height data. Similar results were obtained with whole-tree (all disks in a tree) values (table 2) with the exception being ring SG showing a significant difference (P=0.008) with basal area. ANOVA results for the effect of spacing on the wood quality parameters are shown in table 3. Note that the spacing effects may have been particularly affected by having only one tree representing the lowest and highest spacings. Similar to the other treatments, most of the results show no significant differences at breast height or on a whole-tree basis.

A major factor affecting wood quality parameters for the whole tree, as compared with those only at breast height, is juvenility. The wood formed by trees changes

Table 2—Wood quality data ANOVA for effect of pruning and basal area including mean values, standard deviations (in parentheses), and probabilities (*P*) for breast height and whole tree

			Wood Quality Parameter				
Treatment	Class	*N*	Ring SG	Latewood SG	Earlywood SG	Latewood Percent	Ring Width (mm)
			Breast Height				
Pruning	pruned	7	0.575 (0.041)	0.766 (0.035)	0.348 (0.019)	54.1 (6.5)	2.71 (0.82)
	unpruned	3	0.587 (0.011)	0.780 (0.009)	0.346 (0.016)	55.9 (2.4)	2.87 (0.33)
	P		0.635	0.539	0.869	0.678	0.768
Basal Area	<111	3	0.587 (0.011)	0.780 (0.009)	0.346 (0.016)	55.9 (2.4)	2.87 (0.33)
	111-155	4	0.577 (0.050)	0.763 (0.017)	0.349 (0.024)	54.8 (8.8)	3.06 (0.76)
	>155	3	0.573 (0.036)	0.771 (0.056)	0.347 (0.017)	53.2 (3.0)	2.25 (0.78)
	P		0.895	0.796	0.980	0.869	0.332
			Whole Tree				
Pruning	pruned	7	0.526 (0.010)	0.726 (0.026)	0.337 (0.018)	48.6 (3.5)	2.63 (0.69)
	unpruned	3	0.541 (0.007)	0.758 (0.019)	0.333 (0.015)	49.0 (0.5)	2.91 (0.58)
	P		0.051	0.090	0.757	0.877	0.549
Basal Area	<111	3	0.541 (0.007)	0.758 (0.019)	0.333 (0.015)	49.0 (0.5)	2.91 (0.58)
	111-155	4	0.519 (0.006)	0.719 (0.023)	0.334 (0.019)	48.0 (4.5)	2.91 (0.63)
	>155	3	0.535 (0.007)	0.736 (0.030)	0.341 (0.019)	49.4 (2.3)	2.24 (0.66)
	P		**0.008**	0.178	0.853	0.845	0.360

Significance ($P < 0.05$) is shown in bold.

with age, with the inner wood, so-called juvenile wood, having different chemical, physical, and mechanical properties than that of wood formed later in the life of the tree, so-called mature wood. Intuitively, there is not an abrupt change from juvenile wood to mature wood, thus the term transition wood may be used to classify that wood that is neither juvenile, nor mature. Further complicating matters, annual rings assigned to juvenile wood are not specifically set. In the southern pines, juvenile wood can vary not only between species, but other factors such as region, let alone differences resulting from the use of different criteria (e.g., microfibril angle, specific gravity, latewood percent) for demarcation (Clark 2006). Juvenility in loblolly pine has been well studied while that for longleaf pine has not. Since juvenility can last as long as 20 years for loblolly pine, we used a cambial age of 20 years for each disk to generally classify the wood quality data into predominantly juvenile or mature wood zones.

The effect of spacing on the wood quality parameters from juvenile (≤20 years) and mature (≥21 years) wood zones is shown in table 3. A significant difference is observed at breast height in the juvenile wood (P=0.045), in which the lowest spacing (4.3 feet × 4.3 feet) is significantly different from the other spacings, though this may have been an anomaly, affected by sample size. The most striking differences for the effect of spacing are observed with latewood percent, in which significant differences are observed with the whole-core and mature wood data, both on a whole-tree basis (table 3); however, this should be interpreted with caution given that the seemingly higher latewood percent values at the highest and lowest spacings were provided by only one tree for each. As expected for spacing, an increase in ring width appeared to accompany wider planting densities. Notwithstanding, many reports in the literature draw conclusions on mean values and not statistical comparisons. Results presented here do allow some degree of comparison.

The primary objective of this study was to assess whether there were significant differences between wood quality parameters between the northern and southern cardinal directions. The process of collecting tree cores is often not specified in the literature, presumably because it may be deemed inconsequential. Thus, a core entry point may always be taken in a single cardinal direction, at a position in which a knowledgeable field worker can generate a core from bark to pith (i.e., at the widest diameter), or simply randomly. Knowing that bark thickness has been shown to differ between the northern and southern cardinal directions, but not between the eastern and western cardinal directions (Eberhardt 2013, 2015), a strip of wood was cut from each disk, bark to bark, and through the pith, from south to north (So and others 2010).

Table 3—Wood quality data ANOVA for effect of spacing including mean values, standard deviations (in parentheses), and probabilities (*P*) for breast height and whole tree

Sample	Spacing	*N*	Wood Quality Parameter				
			Ring SG	Latewood SG	Earlywood SG	Latewood Percent	Ring Width (mm)
			Breast Height				
Whole Core	4.3	1	0.542 (—)	0.707 (—)	0.360 (—)	52.5 (—)	1.52 (—)
	5.2	5	0.574 (0.034)	0.777 (0.024)	0.344 (0.020)	53.0 (4.8)	2.68 (0.69)
	6.2	3	0.577 (0.011)	0.775 (0.024)	0.343 (0.018)	54.2 (3.1)	3.06 (0.18)
	13.1	1	0.644 (—)	0.787 (—)	0.362 (—)	66.7 (—)	3.47 (—)
	P		0.171	0.137	0.737	0.118	0.170
Juvenile Core	4.3	1	0.519 (—)	0.680 (—)	0.361 (—)	50.1 (—)	2.08 (—)
	5.2	5	0.575 (0.040)	0.784 (0.026)	0.357 (0.021)	51.1 (6.3)	4.08 (1.16)
	6.2	3	0.574 (0.002)	0.781 (0.023)	0.351 (0.017)	51.2 (0.9)	4.56 (0.50)
	13.1	1	0.600 (—)	0.765 (—)	0.364 (—)	59.4 (—)	5.60 (—)
	P		0.404	**0.045**	0.927	0.542	0.173
Mature Core	4.3	1	0.561 (—)	0.730 (—)	0.359 (—)	54.6 (—)	1.05 (—)
	5.2	5	0.574 (0.033)	0.772 (0.026)	0.339 (0.021)	54.0 (4.0)	1.90 (0.31)
	6.2	3	0.578 (0.017)	0.773 (0.028)	0.337 (0.018)	55.6 (5.4)	2.18 (0.28)
	13.1	1	0.672 (—)	0.801 (—)	0.360 (—)	71.3 (—)	2.13 (—)
	P		0.084	0.387	0.617	0.065	0.083
			Whole Tree				
Whole Core	4.3	1	0.535 (—)	0.701 (—)	0.360 (—)	51.7 (—)	1.60 (—)
	5.2	5	0.532 (0.017)	0.747 (0.025)	0.334 (0.019)	47.8 (2.0)	2.56 (0.57)
	6.2	3	0.528 (0.005)	0.744 (0.013)	0.333 (0.012)	47.3 (1.5)	3.12 (0.27)
	13.1	1	0.526 (—)	0.689 (—)	0.330 (—)	54.6 (—)	3.34 (—)
	P		0.952	0.116	0.538	**0.045**	0.110
Juvenile Core	4.3	1	0.511 (—)	0.690 (—)	0.354 (—)	47.1 (—)	2.12 (—)
	5.2	5	0.523 (0.019)	0.746 (0.024)	0.340 (0.020)	45.2 (2.8)	3.64 (0.92)
	6.2	3	0.517 (0.006)	0.745 (0.010)	0.336 (0.013)	43.8 (1.8)	4.42 (0.40)
	13.1	1	0.497 (—)	0.681 (—)	0.329 (—)	47.4 (—)	4.89 (—)
	P		0.523	0.054	0.788	0.549	0.127
Mature Core	4.3	1	0.567 (—)	0.715 (—)	0.369 (—)	57.9 (—)	0.90 (—)
	5.2	5	0.538 (0.018)	0.745 (0.031)	0.330 (0.018)	49.9 (2.3)	1.69 (0.29)
	6.2	3	0.536 (0.005)	0.744 (0.015)	0.330 (0.012)	49.8 (1.2)	2.06 (0.66)
	13.1	1	0.547 (—)	0.695 (—)	0.330 (—)	59.5 (—)	2.26 (—)
	P		0.358	0.377	0.268	**0.008**	0.198

Significance (P <0.05) is shown in bold.

— = No standard deviation value (*N*=1)

Wood quality parameters measured at breast height are shown in table 4. The lack of a significant difference between the northern and southern directions is the most consistent finding. However, even without significance, the trend for the whole core shows that the northern direction has equal or higher values for all of the wood quality parameters except for earlywood SG. Plotting of the individual data points was carried out to determine if there were any differences from pith to bark that would be lost by comparisons from the whole-core data (fig. 1). Line plots were originally generated (not shown), but trends were difficult to discern, thus smoothing was applied to facilitate the visualization of any possible differences. In general terms, similar plots are obtained for the two cardinal directions, save for the appearance of greater deviation moving further out, through the mature wood zone, towards the bark, while less variation is observed in the transition zone between juvenile and mature wood (fig. 1). Nevertheless, the data in table 4 were still classified into juvenile and mature wood zones. The resultant breast height values also show no significant differences between the northern and southern directions. The same trend of equal or higher values from the northern direction is still true, except that latewood percent is slightly higher for the southern direction in juvenile wood. This might well be the result of the higher earlywood SG in the southern direction causing more of the wood to be classified as latewood. The clearest north-south differences between juvenile and mature wood data arise from ring width

Table 4—Wood quality data paired t-test for effect of direction including mean values, standard deviations (in parentheses), and probabilities (*P*) for breast height and whole tree

		Wood Quality Parameter				
Sample	Direction	Ring SG	Latewood SG	Earlywood SG	Latewood Percent	Ring Width (mm)
Breast Height						
Whole Core	North	0.580 (0.031)	0.774 (0.028)	0.346 (0.020)	54.8 (5.0)	2.81 (0.73)
	South	0.577 (0.040)	0.767 (0.038)	0.349 (0.017)	54.5 (6.9)	2.68 (0.67)
	difference	0.003 (0.020)	0.007 (0.028)	0.003 (0.014)	0.3 (5.0)	0.13 (0.35)
	P	0.650	0.479	0.526	0.860	0.267
Juvenile Core	North	0.572 (0.038)	0.777 (0.041)	0.354 (0.021)	51.4 (6.8)	4.15 (1.21)
	South	0.571 (0.042)	0.765 (0.045)	0.358 (0.019)	52.1 (7.4)	4.15 (1.21)
	difference	0.001 (0.043)	0.013 (0.036)	0.004 (0.020)	0.7 (10.0)	0.00 (0.58)
	P	0.950	0.291	0.539	0.825	0.995
Mature Core	North	0.585 (0.038)	0.772 (0.031)	0.342 (0.021)	56.7 (5.8)	1.99 (0.44)
	South	0.581 (0.044)	0.770 (0.035)	0.343 (0.018)	55.7 (7.6)	1.82 (0.42)
	difference	0.004 (0.023)	0.002 (0.034)	0.001 (0.144)	1.0 (3.6)	0.17 (0.27)
	P	0.577	0.887	0.803	0.426	0.084
Whole Tree						
Whole Core	North	0.535 (0.013)	0.743 (0.029)	0.335 (0.016)	48.9 (3.2)	2.73 (0.65)
	South	0.525 (0.011)	0.727 (0.030)	0.337 (0.017)	48.4 (2.6)	2.69 (0.63)
	difference	0.010 (0.008)	0.016 (0.018)	0.001 (0.004)	0.5 (1.9)	0.04 (0.07)
	P	**0.002**	**0.019**	0.333	0.449	0.096
Juvenile Core	North	0.518 (0.016)	0.739 (0.030)	0.338 (0.016)	44.6 (2.1)	3.85 (1.00)
	South	0.517 (0.017)	0.727 (0.032)	0.340 (0.016)	45.7 (3.2)	3.84 (1.00)
	difference	0.002 (0.008)	0.012 (0.008)	0.002 (0.005)	1.1 (2.4)	0.01 (0.10)
	P	0.511	**0.001**	0.285	0.206	0.733
Mature Core	North	0.548 (0.021)	0.746 (0.033)	0.333 (0.018)	52.2 (4.6)	1.83 (0.54)
	South	0.532 (0.012)	0.725 (0.032)	0.335 (0.020)	50.8 (3.5)	1.71 (0.53)
	difference	0.016 (0.016)	0.021 (0.029)	0.001 (0.006)	1.4 (2.4)	0.12 (0.18)
	P	**0.012**	0.051	0.505	0.095	0.058

Significance (P <0.05) is shown in bold.

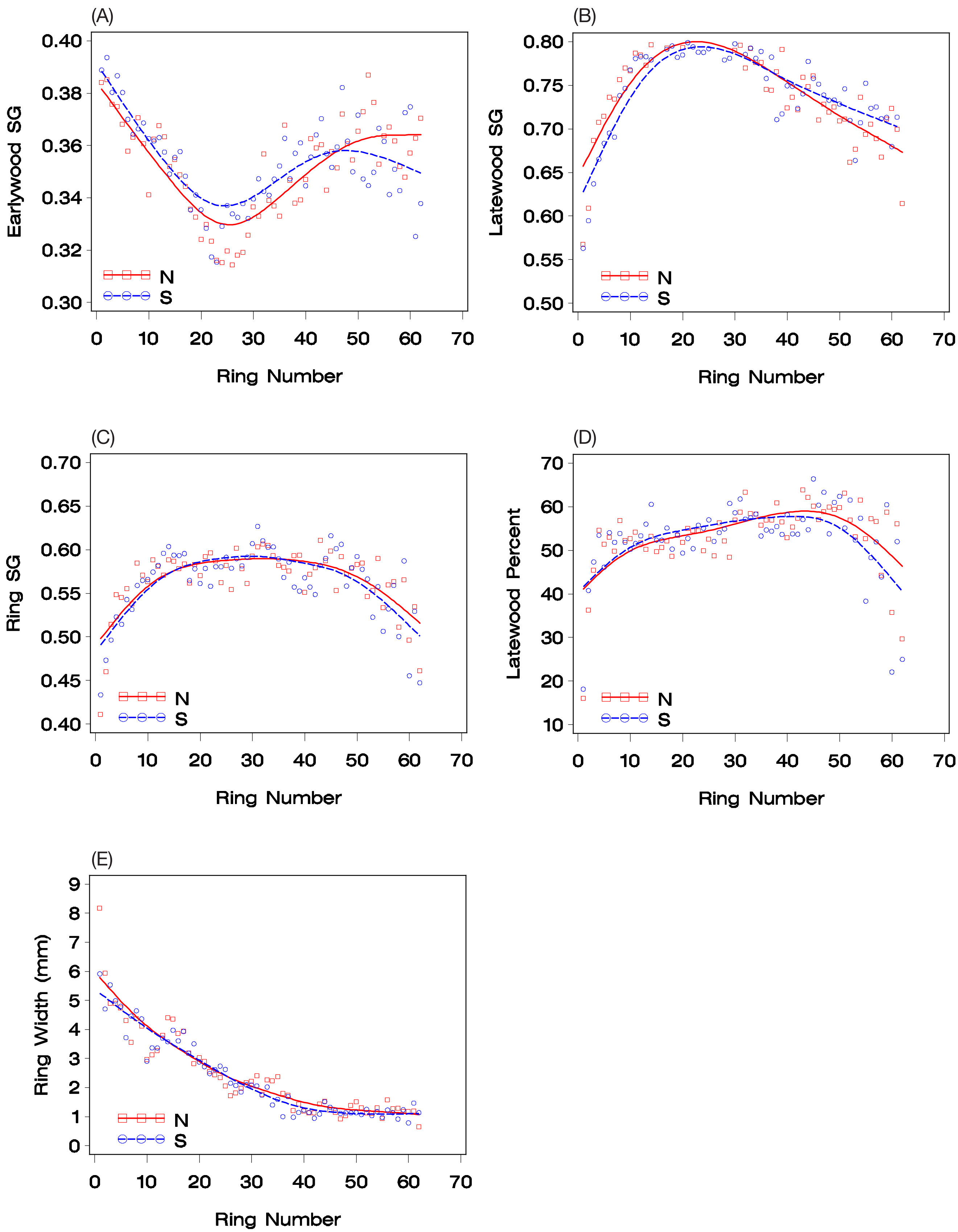

Figure 1—Plot of breast height values of (A) earlywood SG, (B) latewood SG, (C) ring SG, (D) latewood percent and (E) ring width in both the north and south cardinal directions.

data with identical values for the juvenile wood while differences (approaching significance) exist for the mature wood.

Whole-tree values for the wood quality parameters appear lower than those determined at breast height alone (table 4). Intuitively, this is because the data are weighted by the contribution from each wood disk and thus, an increasing contribution from the juvenile wood zone going upwards to the top of the tree is generally expected. These data mirror the trends shown at breast height, but some of the north-south differences are now showing up as significant. For the whole-core data, significantly higher values are now obtained for ring SG and latewood SG in the northern direction; similar results are also obtained for the mature wood data. The ring width observation between juvenile and mature wood match that observed at breast height. Furthermore, ring width for the whole core trends with a seemingly higher mean value in the northern direction compared to the southern direction, following the same trend of a significantly higher thickness for the bark in the northern direction (Eberhardt 2013, 2015). The caveat, herein, is assuming that the asymmetry in wood properties between the northern and southern directions is specifically related to a biological compass applicable to all trees. Indeed, it is impossible to even suggest any causes for the observed differences; however, the results presented here suggest that it would be prudent to be consistent in sampling to avoid any data artifacts that may manifest from repeating patterns of wood property asymmetry in trees.

CONCLUSION

The variability in wood quality parameters for mature longleaf pine trees was investigated using X-ray densitometry. The effect of cardinal direction and treatment (spacing, thinning, and pruning) was assessed, although the number of trees subjected to destructive testing was very limited. The trees were assessed at breast height and on a whole-tree basis. Few significant differences were observed with treatment. Significant differences based on cardinal direction were mostly observed in whole-tree values rather than those at breast height alone, in particular with north-south differences related to ring and latewood SG.

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