Impact of Age and Site Index on Lumber Quality from Intensively Managed Stands

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Abstract

Forests products companies are increasingly buying intensively managed loblolly pine as a raw material source for sawmills and other wood product facilities. Intensively managed loblolly pine has different mechanical properties than loblolly pine from natural stands or from plantations that have not received intensive silvicultural treatments. This study was conducted in 2001 by International Paper to assess the impact of age and site index on lumber quality from intensively managed loblolly pine stands. The study included stands of ages 19, 22, 26, and 30 grown on lands with a site index of 70-75, and ages 19, 22, and 26 from a site index of 80-85. 226 defect-free trees were harvested from these stands in South Carolina and tracked through a Georgia sawmill. The lumber was visually graded then tested in static bending to determine the modulus of elasticity (MOE, a component of stiffness) and modulus of rupture (MOR). Lumber quality improved with age, and by age 26, the dimension lumber was able to adequately meet most stiffness requirements. The stiffness from No. 2 grade lumber from the 70-75 site index sites exceeded those of the 80-85 site index sites at the same stand ages.

Introduction

Lumber design values are incorporated in the National Design Specifications for Wood Construction (NDS), and are accepted by the major building codes (Wallace and Cheung 1989). Design value properties include the modulus of elasticity (MOE, a component of stiffness), bending strength (F_b), tension parallel to grain (F_t), shear parallel to grain (F_v), compression perpendicular to grain ($F_{c\perp}$), and compression parallel to grain (F_c) (AWC 2013). Bending strength (F_b) is calculated from the nonparametric 5th percentile of modulus of rupture (MOR) at 75% confidence combined with a 2.1 safety and uncertainty reduction (ASTM D1990 2007). On June 1, 2013 the NDS for visually graded southern pine lumber changed following testing conducted by the Southern Pine Inspection Bureau (ALSC 2013). The design values were last revised in 1991 following testing conducted from 1977 to 1985 (AFPA 2005; Green et al. 1989). Some of the changes in design values are presented in Table 1. For stiffness, the design values for each grade are calculated from the average values across all sizes obtained from testing developed using the in-grade testing program (ASTM D1990 2007). Thus for any given batch of lumber approximately 50% of the pieces may be below the design values. The design values for MOE are of particular importance when evaluating plantation lumber as stiffness appears to be most limiting in younger stands.

Table 1. Summary of 1991 and 2013 design values for visually graded southern pine lumber

Size	Grade	1991 MOE (million psi)	2013 MOE (million psi)	1991 Bending Strength F_b (psi)	2013 Bending Strength F_b (psi)
2x4	Select Structural	1.8	1.8	2850	2350
	No. 1	1.7	1.6	1850	1500
	No. 2	1.6	1.4	1500	1100
2x6	Select Structural	1.8	1.8	2550	2100
	No. 1	1.7	1.6	1650	1350
	No. 2	1.6	1.4	1250	1000
2x8	Select Structural	1.8	1.8	2300	1950
	No. 1	1.7	1.6	1500	1250
	No. 2	1.6	1.4	1200	925
2x10	Select Structural	1.8	1.8	2050	1700
	No. 1	1.7	1.6	1300	1050
	No. 2	1.6	1.4	1050	800
2x12	Select Structural	1.8	1.8	1900	1600
	No. 1	1.7	1.6	1250	1000
	No. 2	1.6	1.4	975	750

In the 1990s considerable effort was expended to increase growth rates in loblolly pine through silvicultural intensity; during this time profitability also increased markedly. Silviculture intensity included increased tillage, competition control, and repeated fertilization targeted at a productivity rate of 8 green tons/acre/year. Many corporate lands are suited for high productivity plantation management and thus a high proportion of established plantations have been managed intensively since the mid 1990's. More recently the approach to land management has been modified to match the investment goals of new institutional landowners.

Because of the increase of silvicultural management, trees can now reach merchantable size for chip-n-saw or sawtimber in as little as 16 years (Clark et al. 2008; Vance et al. 2010). The mechanical properties of wood from younger rapidly grown plantations are typically lower than from natural stands as the trees have more juvenile wood (USDA 1988; McAlister and Clark 1991; Larson et al. 2001). Lumber stiffness is typically low in younger aged stands (Olsen et al. 1947); these attributes serve the young tree well by imparting considerable flexibility to the bole. However, these same characteristics are detrimental in structural products where high stiffness is desirable.

Several studies have been undertaken to determine likely impacts on lumber grade and mechanical properties from younger loblolly pine stands. A review was completed of various public domain projects that have sawn plantation-grown loblolly pine from stands aged 14 to 40 years (Table 2). While the procedures followed in these studies differ, they collectively illustrate that, as age increases, lumber stiffness and the proportion of lumber in the higher visual grades (No. 2 and better) increase. Most southern pine sawmills typically produce 70 to 80% in the No. 2 and better grades, so a high proportion of younger aged logs in the delivered log mix would be detrimental to a mill producing structural grade material. Low stiffness in these young ages also severely limits the production of premium value Machine Stress Rated (MSR) or Machine Evaluated Lumber (MEL) grades.

Table 2. Summary of visual grade production and stiffness from various studies of grade out-turn from stands aged 14 to 40 years.

Timber Age	State	Site Index (*Dominant Tree Height Age 25*)	Products	Visual grades % No. 2 and better	Stiffness	Reference
14	Georgia	-	1x4, 1x6, 2x4, 2x6	66-80%	100% below grade design requirements	Clark et al. 1998
15	South Carolina	-	5/4x4, 2x4	-	Inner boards 0.78E Outer boards 1.43E	Pearson and Gilmore 1980
22	Georgia	85 ft	2x4, 2x6	72%	No. 2 Av MOE for two reps, 1.35 and 1.63	Clark et al. 1996
24	Georgia	-	1x4, 1x6, 2x4, 2x6	93%	94% No. 1, 88% No. 2, 64% No. 3 below MOE design requirements	Clark et al. 1998
25	South Carolina	-	5/4x4, 2x4	-	Inner boards 0.89E Outer boards 1.54E	Pearson and Gilmore 1980
25	Alabama	67 ft	2x4, 2x6, 2x8	-	22% 2x4, 2x6 meet design values	Biblis et al. 1993
28	North Carolina	69 ft	2x4	-	No. 1 1.32E No. 2 1.25E No. 3 1.22E	Kretschmann and Bendtsen 1992
28	Georgia	83 ft	2x4, 2x6	72%	No. 2 Av MOE for two reps, 1.29 and 1.68	Clark et al. 1996
30	Alabama	69 ft	2x4, 2x6, 2x8	-	43% 2x4, 2x6 meet design values	Biblis et al. 1993
35	Alabama	70 ft	2x4, 2x6, 2x8	-	52% 2x4, 2x6 meet design values	Biblis et al. 1993
40	Georgia	70 ft	2x4, 2x6	79%	No. 2 Av MOE for two reps, 1.93 and 1.79	Clark et al. 1996

Economic evaluations typically favor intensive regimes that produce a high volume of wood with relatively short rotation age. These regimes can produce a higher proportion of relatively large saw logs at an earlier age than less intensively managed stands. However, logs of similar dimensions but of different ages produce different qualities of lumber when sawn. To better assess the impact of harvest age and site index on yield and quality of lumber from intensively managed stands, a study was conducted in 2001 that tracked trees from known stands and site indices through to the final lumber products. The results of the study will be compared to both the previous (1991) and new (2013) design values.

Materials and Methods

In 2001, 223 trees were felled from seven stands in the lower coastal plain of South Carolina and sawn in Georgia. The maximum time between harvest and sawing was sixteen days. The stands targeted for this study were loblolly pine plantations in two distinct site index (25 years) classes, either 70-75, or 80-85, with all stands having received good competition control combined with thinning and fertilization. Stand ages for this trial were 19, 22, and 26, in each of the two site index classes, and a 30 year old stand in the low site index class (Table 3). Trees of good form across the range of diameter classes were selected in each stand. The selection process excluded trees with defects (major scars, forks, and significant sweep). Sample trees were measured for diameter at breast height (4 ½ feet) outside the bark (DBH) and total height (Table 4). A maximum of nine trees per two-inch diameter class were selected across the diameter range. The selection area of the sample trees was deliberately constrained both to reduce the problems associated with the removal of these trees from the site and to contain tree selection with a known site index range. In some cases this may have limited the numbers of trees selected in the larger diameter classes.

Table 3. Numbers of samples trees selected per diameter class in each stand.

Stand	Age (Years)	Site Index Class	Number of Sample Trees per DBH Class 8	10	12	14	16	18	Average Total Height (Feet)
19L	19	70 – 75	9	9	9	6	--	--	63
22L	22	70 – 75	9	9	7	3	--	--	68
26L	26	70 – 75	7	9	9	9	2	--	75
30L	30	70 – 75	--	3	9	9	8	1	79
19H	19	80 - 85	9	9	9	8	--	--	72
22H	22	80 - 85	--	9	9	7	2	--	72
26H	26	80 - 85	--	7	9	9	7	2	82
Total trees			34	55	61	51	19	3	

Harvesting was conducted with a tree harvester equipped with a saw head. The trees were felled, limbed, and extracted by grapple skidder to the road edge. Care was taken by the logging contractor to minimize tree damage at each of these stages. During this time it was determined that one stand, in spite of its classification in the inventory as loblolly in fact contained a proportion of slash pine (stand 22L - age 22, low site index). Trees from this stand were processed in the same way as all other trees.

The trees were sorted into batches and then transferred to the mill and laid out in random but identifiable batches, with each batch consisting of a single diameter class from a single stand (Figure 1). Each batch was run through the green end using the then current mill optimization standards. All of the lumber was labeled so it could be identified back to the lumber position in the cutting pattern, the log and the log's position in the tree, the tree, and the stand. Market volatility causes lumber prices to be inconsistent, but often wide dimension lumber commands a premium price over narrow dimension lumber. This premium is becoming more established as average log size decreases and thus production of wide dimension lumber decreases. The distribution of lumber sizes produced from a given stand can have dramatic impacts on mill profitability. Radius edged decking (5/4 x 6) is generally an item that has seasonal demand, but when the demand is high, prices tend to be among the highest per MBF of any item sawn in a typical dimension sawmill. For this study, decking production was a priority in the sawing process. For each log, the canter operator made a decision to cut either decking or 2" and 4x4's based on visual grading of a cant. High-grade cants were processed to produce decking, while lower grade cants were cut into 2" or 4x4's. As with decking, the market for 4x4's can be seasonally volatile, but typically a market does exists for some quantity of 4x4's year round. This allows sawmills to produce 4x4's to some extent at any time. This helps the mill when running lower grades of logs, because the grade rules regarding knot sizes for 4x4's allow some of this product to grade into a No. 2 or better grade, but would likely fall into a lower grade if cut into a 2x4. Often in a sawmill 1" finishing lumber is not a preferred item. While 1" finishing lumber tends to have a high sales price in the higher grades (C and D), 1" is often cut more as a recovery item and is preferred as almost any solid wood piece has more value than an equivalent quantity of chips. 1x4's were the 1" product sawn for this study.

Figure 1. One batch of trees, 14-inch class from Stand 26H, segregated and ready for processing.

The lumber was dried to a target of 15% moisture content, planed (but not trimmed), then shipped to Timber Products Inspection (TP) in Conyers, Georgia where it was graded and tested for mechanical properties (MOE and MOR). Visual grading was completed by experienced TP staff using both National Grading Rules, and International Paper variants (mostly associated with tighter wane requirements). The 2x4 and 2x6 lumber was measured for moisture content then tested to failure in a Metriguard 312 static bending proof tester for edge-wise MOE and MOR values according to ASTM D4761 (2011).

Results and Discussion

Lumber size distribution

Table 4 and Figure 2 show the lumber size distribution for each stand. Each age class consistently produced a higher proportion of narrow dimension lumber (2x4's) from the low site index stands and conversely, a higher proportion of wide dimension from the high site index stands. All of the high site index stands produced 2x10 material, while only the 30 year old low site index stand produced 2x10 material. Additionally, the data show higher production of 5/4 x 6 radius edge decking from the high site index stands. At a given harvest age, a higher site index produced a lumber mix that was favorable to the sawmill with regard to manufacturing cost and resulted in the highest sales realization for each MBF of lumber produced and sold.

Table 4. Comparison of lumber distribution by size (in percent).

Source	Lumber Dimension by Percent of Total Lumber Produced							
	1 x 4	2 x 4	2 x 6	2 x 8	2 x 10	2 x 12	4 x 4	5/4 x 6
Stand 19L	7	51	13	2	-	-	19	8
Stand 19H	7	47	15	1	1	-	17	12
Stand 22L	6	43	30	-	-	-	16	5
Stand 22H	6	42	22	3	3	-	14	11
Stand 26L	5	39	24	5	-	-	13	15
Stand 26H	5	33	26	6	4	-	9	18
Stand 30L	3	23	36	10	12	2	6	8

Visual Grade Yields

Grade distribution is extremely important since it is the primary determinant of value. Visual grades are influenced by many factors including lumber quality and size. Larger trees can yield wider lumber and wider lumber allows a larger knot for a given grade. For example, for a 2x4 to make a No. 2 grade, a centerline knot is limited to 7/8", while a No. 2 2x6 allows a 1-7/8" centerline knot, progressing to a No. 2 2x12, which allows a 3" centerline knot (SPIB 1994). Two statistics often used by sawmills to track performance are the percentages of dimension lumber that grade either as No. 1 and better or No. 2 and better. Table 5 shows the percent of the 2" lumber that was graded as No. 1 and better and the percent of the 2" lumber that graded as No. 2 and better. The yield of higher grades of lumber is critical to sawmill profitability. The results of percent No. 1 and better and percent No. 2 and better for both 2x4 and 2x6 show that the lower site index outperforms the higher site index for a given age class. While the lower grade yield percentages would suggest a lower value for the higher site indices, higher yields per acre for the higher site indices result in a higher land expectation value for a high site index of a given age. The proportion of No. 1 and better, and No. 2 and better from the loblolly pine stands increased with age. The largest increase is from the age 19 to 26, after which the proportion of higher grades is more consistent.

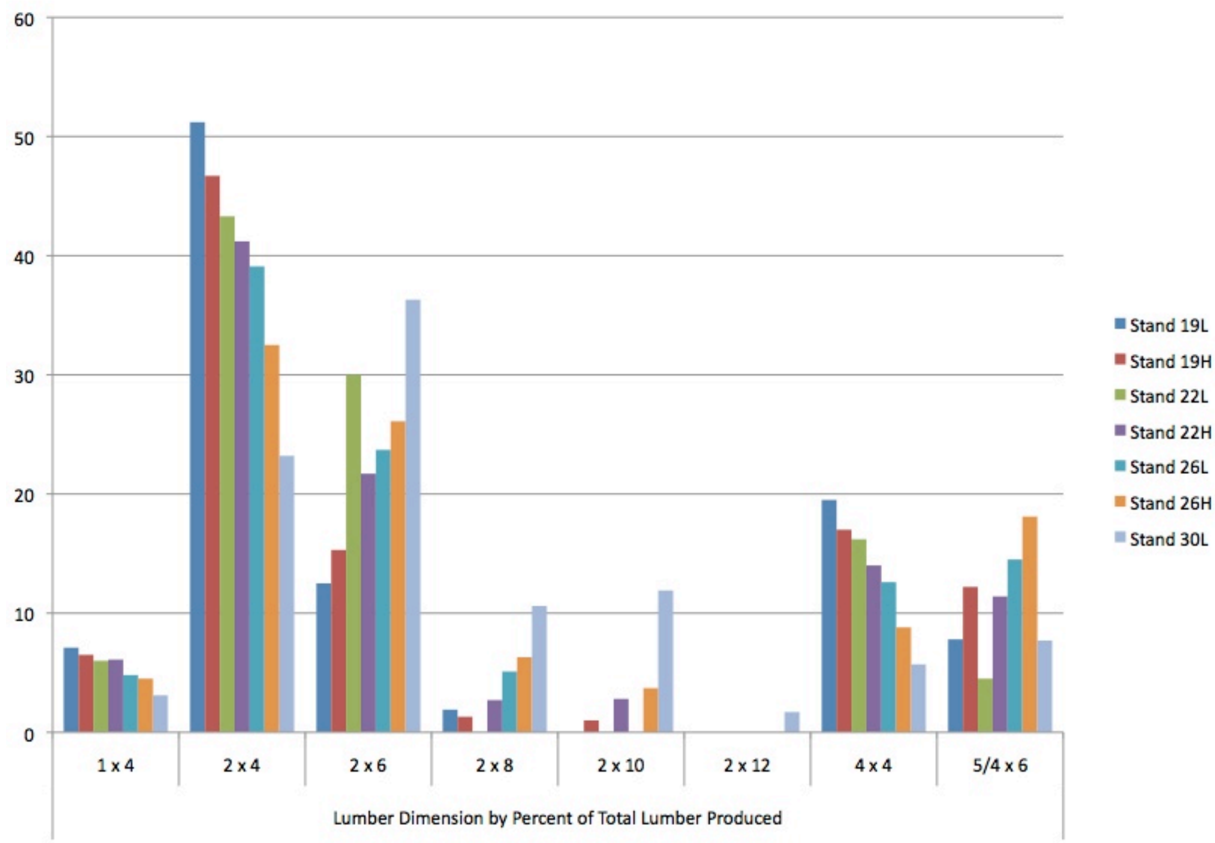

Figure 2. Lumber distributions by dimension for all stands

Table 5: Percent of 2" lumber graded as No. 1 and better and No. 2 and better

Grade	Source	Size					
		2 x 4	2 x 6	2 x 8	2 x 10	2 x 12	All 2"
No. 1 & Btr.	19L	35	39	63	-	-	37
	19H	30	27	46	75	-	31
	22L	53	78	-	-	-	60
	22H	27	47	75	69	-	44
	26L	45	54	90	-	-	51
	26H	38	44	61	74	-	46
	30L	45	47	55	54	0	47
	All Test Stands	40	46	62	64	0	45
No. 2 & Btr.	19L	77	90	63	-	-	80
	19H	42	78	74	94	-	75
	22L	83	92	-	-	-	86
	22H	82	87	87	100	-	79
	26L	78	93	100	-	-	84
	26H	78	88	97	100	-	86
	30L	74	90	86	91	0	83
	All Test Stands	76	88	89	95	0	82

A further breakdown of the machine and visual grade distributions for all of the 2" lumber produced from the seven stands processed in this study are shown in Table 6. Relative value tends to increase as grade improves and length increases (Random Lengths 2013); for example MSR 2250f-1.9E typically has higher value than No. 1 grade and No. 1 grade has higher value than No. 2 grade, etc. In 2001 for southern pine 2x4 lumber, No. 1 grade material was worth 22% more than No. 2 lumber, 61% more than No. 3 lumber, and over 300% more than No. 4 lumber (Random Lengths 2003). In 2012 the differences were less pronounced with No. 1 grade 2x4 material was worth 11% more than No. 2, 30% more than No.3, and 56% more than No. 4 material (Random Lengths 2013). The lumber that met the machine graded 2250f-1.9E grade (2250f refers to a bending strength of 2250 psi, 1.9E refers to a stiffness of 1.9 million psi) was relatively low while many of the pieces met the visual grading requirements for the Select Structural (SS) grade. For prime lumber, many consumers purchase prime lumber because these grades have more stringent specifications on the amount of allowable wane. Again the results show that the lower site index outperforms the higher site index for a given age class however the increase in volume results in favorable economics for the high site index stand.

Table 6. Lumber grade distribution percentages for 2 x 4, 2x6, 2x8, and 2x10's.

Size	Source	Grade							
		MSR 2250f-1.9E	SS	No. 1 Prime	No. 1	No. 2 Prime	No. 2	No. 3	No. 4
2x4	19L	-	13	11	9	24	18	189	9
	19H	-	14	8	8	24	19	19	9
	22L	7	23	14	9	16	15	9	7
	22H	-	21	4	11	20	15	21	7
	26L	2	25	8	11	17	16	15	7
	26H	3	17	6	12	21	19	17	5
	30L	6	23	4	12	13	16	18	7
	All Test Stands	2	19	8	11	19	17	17	7
2x6	19L	-	12	10	17	27	23	8	3
	19H	-	12	2	12	28	24	16	6
	22L	5	50	11	11	11	3	4	4
	22H	-	30	10	7	26	14	13	1
	26L	1	36	8	10	27	11	7	1
	26H	-	20	9	15	29	16	10	2
	30L	4	19	10	14	28	16	8	2
	All Test Stands	1	24	8	13	27	16	9	2
2x8	19L	-	49	-	14	-	-	-	37
	19H	-	46	-	-	15	13	11	15
	22L	-	-	-	-	-	-	-	-
	22H	-	64	11	-	13	-	4	9
	26L	-	62	29	-	10	-	-	-
	26H	-	42	16	3	27	10	3	0
	30L	-	40	11	4	18	13	7	7
	All Test Stands	-	46	13	3	18	9	4	7
2x10	19L	-	-	-	-	-	-	-	-
	19H	-	-	-	75	19	-	6	-
	22L	-	-	-	-	-	-	-	-
	22H	-	36	-	33	31	-	-	-
	26L	-	-	-	-	-	-	-	-
	26H	-	42	15	17	26	-	-	-
	30L	8	30	16	-	31	5	3	6
	All Test Stands	4	32	13	15	29	3	2	3

Table 7 shows the decking grade distribution produced for each stand. The data indicate that stands harvested at age 26 yield more Premium grade and less Low Grade decking material than stands harvested at an earlier age.

Table 7. Lumber grade distribution percentages for 5/4 x 6 Radius Edge Decking.

Source	Grade		
	Premium	Standard	Low Grade
19L	11	70	19
19H	7	70	24
22L	-	100	-
22H	13	77	10
26L	14	78	8
26H	16	74	10
30L	13	76	11
All Test Stands	13	75	12

The grade distribution of 4x4's from this test is shown in Table 8. With respect to age, the data show that the older stands produce 4x4's with a higher percentage of No. 2 and better grades. The results with respect to site index are inconclusive.

Table 8. Lumber grade distribution percentages for 4 x 4's.

Source	Grade			
	1	2	3	4
19L	59	35	1	6
19H	49	40	5	7
22L	58	33	9	-
22H	57	37	4	1
26L	69	28	3	-
26H	61	39	0	-
30L	65	29	5	2
All Test Stands	60	34	4	2

Table 9 shows the grade distribution for 1x4's produced.

Table 9. Lumber grade distribution percentages for 1 x 4's.

Source	Grade				
	C	D	2	3	4
19L	4	14	70	11	2
19H	4	11	63	22	-
22L	2	23	63	12	0
22H	4	17	64	14	1
26L	15	12	61	10	2
26H	7	16	69	8	0
30L	8	15	59	16	2
All Test Stands	7	15	64	13	1

Recovery of Prime Grades in Dimension Lumber

The larger the tree's size the more prime grade is likely to be produced. Prime grades as a proportion of the total No. 1 and No. 2 volume were consistent at about 40% for all stands, except for the larger trees of the 26 year-old high site index, and the 30 year-old stand, where the proportion of prime grades increased to 49%.

Table 10 shows the percentage of 2" lumber that graded as No. 1 Prime grade for each width for each stand. Table 16 shows similar data for No. 2 Prime for each width. For each of the test stands, all lumber was graded to its highest potential grade.

Table 10. Percent of the 2” lumber graded as No. 1 Prime and No. 2 Prime.

Grade	Source	Size					
		2 x 4	2 x 6	2 x 8	2 x 10	2 x 12	All 2"
No. 1 Prime	19L	12	10	-	-	-	11
	19H	8	2	-	-	-	5
	22L	14	11	-	-	-	13
	22H	4	10	11	-	-	6
	26L	8	8	29	-	-	9
	26H	6	9	16	15	-	9
	30L	4	10	11	16	-	9
	All Test Stands	8	9	13	13	-	9
No. 2 Prime	19L	24	27	-	-	-	23
	19H	24	28	15	19	-	25
	22L	16	11	-	-	-	14
	22H	20	26	13	31	-	22
	26L	17	27	10	-	-	20
	26H	22	29	26	26	-	25
	30L	13	28	18	31	-	22
	All Test Stands	19	27	18	29	-	22

Recovery of Machine Stress Rated (MSR) Grades

MSR recovery levels of MSR grades 2400f-2.0E and 2250f-1.9E in the loblolly pine plantation stands were negligible (<1%) in all but the 30 year-old stand (30L) that produced 5% MSR grade lumber by volume. A mill receiving a high proportion of its logs from young stands will struggle to produce marketable quantities of the higher stiffness and strength MSR grade lumber. The single loblolly-slash stand (stand 22L) within this study produced 6% of its dimension lumber in MSR grades illustrating the slight stiffness advantage of slash pine over loblolly pine at younger ages.

Lumber Stiffness

In general, lumber stiffness increased with age. Stands on a higher site index had a lower average stiffness than stands of the same age on a lower site index. The 2x4 dimension lumber from all stands on the higher site index had average MOE values below the 1991 design values (No. 1 = 1.7E, No. 2 = 1.6E, and No. 3 = 1.4E) (AFPA 2005). A mill that received a substantial proportion of its logs from stands younger than age 26 or from quality high sites would likely have had difficulty maintaining the old MOE design values for No. 1 and No. 2 dimension lumber (Figure 3).

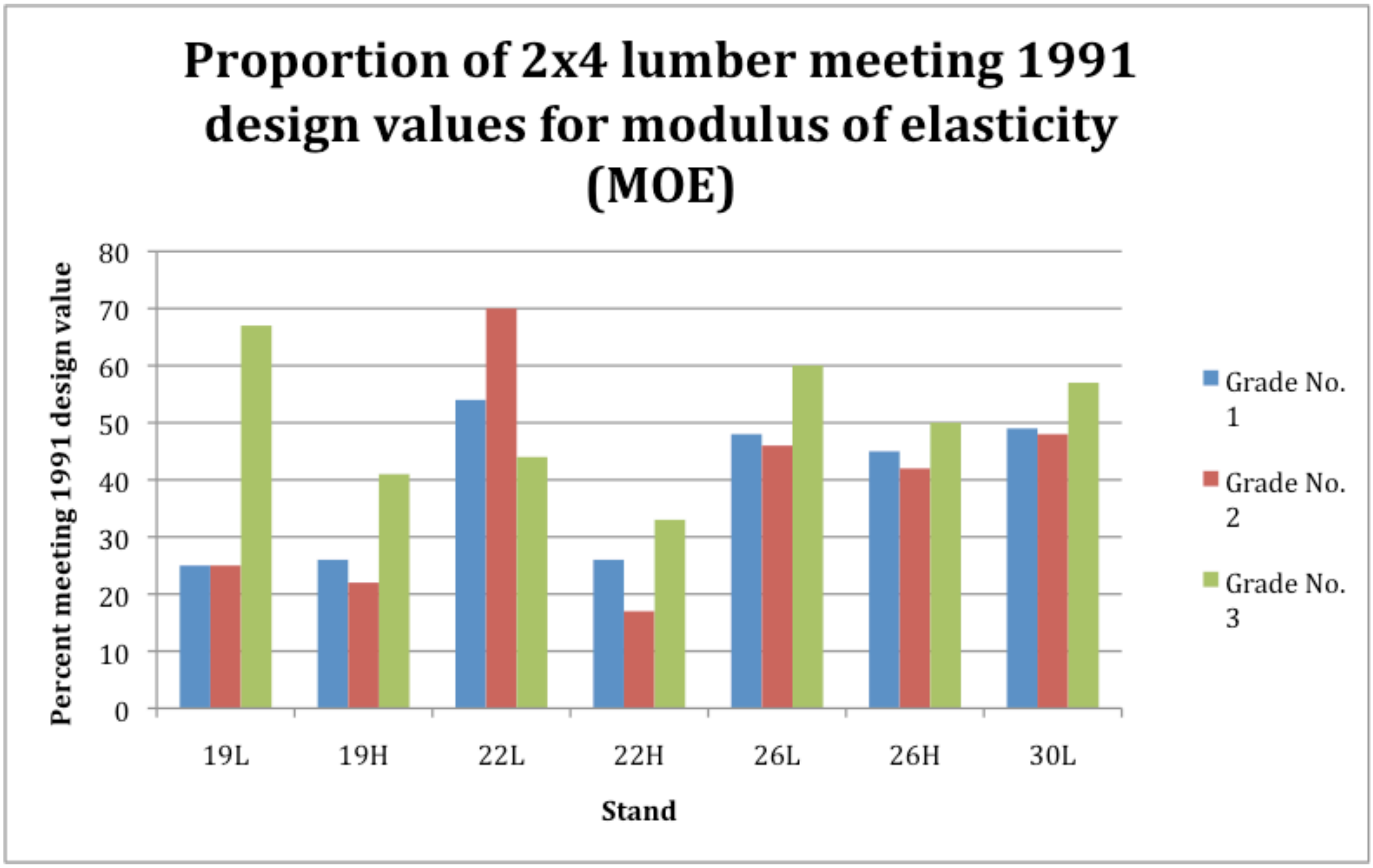

Figure 3. Proportion of 2 x 4 lumber meeting 1991 MOE design values.

Impact of Prime Grades on Lumber Stiffness

Prime grades were lower in stiffness than the standard grades by approximately 10% comparing No. 1 with No. 1 Prime, and by 13% when comparing No. 2 with No. 2 Prime. Prime grades have less wane than standard grades as they tend to be cut from the center of the log and thus have lower stiffness. Analysis of the results from the recent testing by SPIB in the No. 2 2x4 size and grade also show similar differences between No. 2 Prime lumber and No. 2 lumber (ALSC 2011); both grades have the same design values (ALSC 2013).

Lumber Bending Strength (F_b)

Similar to MOE requirements, dimension lumber should achieve a specified bending strength (F_b) such that ninety-five percent of the pieces in a population exceed these limits. In 2001 these were 1850 psi, 1500 psi, and 850 psi for grades No. 1, No. 2, and No. 3 respectively, in 2x4 dimension lumber. The results varied but generally bending strength increased with age, particularly in the No. 2 grade. The No. 1 grade and No. 3 grade material had conflicting results which was likely the result of the relatively small sample sizes in these populations. The results from the low site index stands and the higher site index stands were inconclusive as the lumber from the higher site index stands was generally stronger at ages 19 and 22 while slightly weaker at age 26.

Table 11. Proportion of 2×4 lumber exceeding 1991 ASD F_b design specifications.

Stand	Grade		
	No. 1	No. 2	No. 3
19L	97	87	94
19H	95	91	100
22L	95	91	100
22H	100	97	100
26L	95	98	74
26H	90	95	86
30L	86	96	100

Stand Specific Design Standards for Dimension Lumber

The results of destructive testing all of the 2-inch dimension lumber from this trial were used to calculate the 2-inch No. 2 grade design values for F_b and MOE for each stand, as a separate population. These were developed by the USDA Forest Service Forest Products Laboratory and codified in ASTM D1990 'Establishing Allowable properties for Visually-graded Dimension Lumber from In-Grade tests of Full Size Specimens' (ASTM 2007). The procedures followed in this study were those described by Evans et al. (2001).

The MOE values are rounded to the nearest 100,000 psi (ASTM 2007). The bending strength (F_b) design value is based on the test values obtained from edge-wise bending to failure. These were all corrected to 15% moisture content, adjusted to a standard size, then the 75% lower tolerance level of the 5th percentile of the sampled population was calculated. This value is divided by 2.1 to allow for in-service defects finally resulting in the F_b design value for the population.

The sample size used for these stand level analyses ranged from 51 to 174. The In-grade testing protocol recommends a sample size of 360; however the results should be adequately robust to enable comparison to the design values.

Table 12 indicates that design values F_b and MOE for the loblolly pine stands were below those published in 1991 for southern pine except for the 30-year-old stand and the 22 year-old loblolly-slash mixture. The remaining stands met the 2013 F_b design value. The 19L stand met the 2013 MOE design value while the 19H and the 22H stands did not meet the new design value however they were relatively close to meeting the value. These results indicate that, where stiffness and strength will be an issue for dimension grade lumber, preference should be given to logs obtained from stands 26 years old and older. However it is not known from these results at what age, from 22 to 26, that stands would meet the new design values.

Table 12. Comparison of stand specific design values for 2×4 and 2×6 No. 2 grade with the 1991 and 2013 No. 2 southern pine design values.

Stand Age, Site Index	Dimension	Stand specific design values		1991 design values		2013 design values	
		F_b (psi)	MOE (million psi)	F_b (psi)	MOE (million psi)	F_b (psi)	MOE (million psi)
19L	2x4	1350	1.4	1500	1.6	1100	1.4
	2x6	1100	1.4	1250	1.6	1000	1.4
19H	2x4	1400	1.3	1500	1.6	1100	1.4
	2x6	1150	1.3	1250	1.6	1000	1.4
22L	2x4	1550	1.6	1500	1.6	1100	1.4
	2x6	1300	1.6	1250	1.6	1000	1.4
22H	2x4	1350	1.3	1500	1.6	1100	1.4
	2x6	1100	1.3	1250	1.6	1000	1.4
26L	2x4	1400	1.6	1500	1.6	1100	1.4
	2x6	1150	1.6	1250	1.6	1000	1.4
26H	2x4	1450	1.5	1500	1.6	1100	1.4
	2x6	1200	1.5	1250	1.6	1000	1.4
30L	2x4	1600	1.7	1500	1.6	1100	1.4
	2x6	1350	1.7	1250	1.6	1000	1.4

Summary

The effect of management intensity and age on lumber yield and quality was examined with lumber sawn from stands of similar ages that differed primarily in growth rate. At a given age, trees with higher growth rates (i.e., those on better sites with larger trees) produced a lumber mix that was favorable to the sawmill with regard to manufacturing cost and resulted in the highest sales realization for each MBF of lumber produced and sold. While the production of No.1 and No. 2 and better grades was slightly higher for the slower growing trees, this difference was not sufficient to overcome the value loss due to lower lumber volume.

Lumber stiffness was found to increase with age, but at a given age stiffness was lower for trees grown on high quality sites. Study trees growing on lower site qualities had calculated design values equal to the 1991 values after 22 years; however this stand had some slash pine which perhaps skewed the results higher. The trees growing on higher site qualities did not achieve the 1991 MOE design values. The calculated MOE design values for trees at least 26 years old met the 2013 revised design standards, regardless of site quality, with stands from lower site qualities meeting the design standards at ages as young as 19 years. Calculated F_b design values from the study trees met the 2013 F_b design standard at all ages and site qualities. Given the new design standards, it seems likely that, for integrated companies seeking to optimize investments from the forest through the mill, intensive management will provide higher enterprise returns as higher board-foot volume production overshadows reduction in physical properties. For mills that are able to access market wood of various ages within a consistent size range at a consistent price, there may be opportunities to improve physical properties of the lumber produced by favoring slower-growing stands.

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