CONSEQUENCES OF A FIXED-TOP DOB ASSUMPTION ON THE ESTIMATION OF PINE CHIP-N-SAW AND SAWTIMBER TONS

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Abstract—Many pine plantation growth and yield simulators allow the user to define products based on the size classes and top diameters corresponding to local market specs. Top d.o.b. is typically set at a constant corresponding to the local product specification. Examination of individual tree data collected in cruises of loblolly pine stands across the South show that the top d.o.b. for pine products is not a constant, but varies directly with d.b.h. Median overstatement of individual tree PST volume due to use of a fixed 6 inch d.o.b. top instead of the top d.o.b. implied from merchantable height is about 10 to 15 percent, but can range from zero to almost 400 percent. Volume overstatements at the stand level are more muted. PST is in the range of 0-149 percent and with a median value of about 16 percent. CNS and PPW have smaller ranges (0-60 percent) and median overstatements of about 8-10 percent. These overstatements are inversely related to the ratio of merchantable height divided by total height. PST overstatement was less than ten percent only when height ratio averaged 0.75 or more. Overstatements of 100 percent or more occurred when the product height ratios drops below about 0.35. Overstatements are not associated with stand attributes or geographical location in any meaningful way.

INTRODUCTION

Pine products generally recognized in the South include pulpwood (PPW), chip-n-saw (CNS), and sawtimber (PST). Other products including canter wood, poles, ply-logs, etc. may be recognized as well depending upon geographical location or market region. However a discussion of them is not germane to this paper.

Each of these products is defined in the market by d.b.h., a minimum merchantable height and a minimum top diameter. In addition certain quality characteristics must be present before a tree can qualify for CNS or PST. These include straightness, and the absence of large limbs, surface defect, ring or whorled knots, and forks within the portion of the stem associated with these two products.

Merchantable height may be limited by the top d.o.b. associated with the product specification or by the quality factors just mentioned. One definition of merchantable height is that point where the sum of branch diameters within any one-foot section exceeds some percentage of stem diameter at that point and where there is less than eight feet of clear stem large enough to qualify above that point. Values range from thirty percent (pers. comm., Tom Carignan, Carignan Forestry Consultants, www.Carignan.net) to one hundred percent (Clark and McAlister 1998).

Growth and yield models are widely used to provide estimates of product volume. Examples of these models include Baldwin and Feducia (1987), Burgan and others (1994), Burkhart (2003), Chang (2005), and many others. Citations are meant to be examples, and are by no means exhaustive.

The merchandising routine of these models calculates product volume to the top d.o.b. specified by the user for each product. That value is generally set at the value called for by each product. That same assumption is occasionally made in working up a cruise.

This analysis evaluates whether it is reasonable to assume that products terminate at the top d.o.b. used to define the each product, and if not, the magnitude of bias that may be expected to occur when that assumption is not met.

METHODS

Data for this analysis came from stand level cruises done by experienced cruisers. More than 3,000 stands across the South were inventoried using commonly accepted practices. Prism plots were always used, and prism factors were either 10 or 20, depending upon stand basal area. D.b.h. was estimated to the nearest inch, and merchantable height was estimated to the nearest half-log. Total height was measured across a range of diameters in some stands and for dominant and codominant trees in other stands. Merchantable height was not estimated for some stands; instead cruisers estimated the diameter at the merchantable top. Site quality was determined for each stand in an independent process.

Product calls were based on individual tree quality and local product specs. The CNS diameter range was 8 to 11 inches and the PST diameter range was 10 inches and larger. Consequently trees in the 10- and 11-inch classes could represent either product. In general, the 10-inch minimum sawtimber d.b.h. occurred in areas west of the Mississippi River where CNS was generally not recognized.

Analysis was done both at the tree level and at the stand level. The tree level analysis was restricted to a 9,600 tree subset of loblolly pine with data for both total and merchantable height. Trees in this subset were from both planted and natural stands, and were in geographical regions where the product specification for PST was either a 6-inch or an 8-inch d.o.b. top. The top d.o.b. of each tree in this subset was calculated by a taper equation developed for planted loblolly stands that had been thinned (Baldwin and Feduccia 1987). Almost three percent of the trees in this subset had a calculated top d.o.b. that was in the 4-inch class or smaller. These trees were discarded from the

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analysis. About 16 percent of the trees had a calculated top d.o.b. in the 5-inch class, and these trees were retained in the analysis. A factorial ANOVA was done to evaluate the main effects of d.b.h., origin, the spec top d.o.b. along with their interactions on the top d.o.b. estimated by the taper equation. All statistical analysis was done using procedures in STATISTIX 8.0 (Anonymous).

The stand level analysis was restricted to loblolly pine plantations occurring in geographical regions where the product specification for top d.o.b. was 6.0 inches for both CNS and PST. About 1,200 stands cruised with ten or more plots from the 3,000 stand dataset were used for this analysis. Merchantable tons by product were calculated for each stand under two different assumptions of top d.o.b. One was to assume that the top d.o.b. went to the 6.0 inch top specified for each product. The other way was to use the top d.o.b. calculated by the same taper equation used in the tree level analysis. If the calculated top d.o.b. was less than the product specification, then the product specification was used. These two workup methodologies are referred to as fixed top and variable top workups respectively.

Since total height was collected on only a small number of trees, it was estimated for the remaining trees with the lower coastal plain diameter-total height equation reported in Harrison and Borders (1996). That equation in turn requires information about dominant height, which was not measured as part of the cruise protocol. Consequently it was estimated for each plot by different methodologies. These were in decreasing order of priority, a) average total height of measured trees at each plot whose diameters were at least as large as plot qmd, b) as above, but for trees whose total height was estimated by a diameter-total height equation developed for stands with such data, c) the average height calculated by either of the two previous methodologies, d) the average total height of measured trees in stands where the diameter-total height equation was not significant, or e) the dominant height implied by stand age and site quality.

RESULTS AND DISCUSSION

Tree level

Results from the factorial ANOVA evaluating the main effects of d.b.h., stand origin, and spec top d.o.b. on the calculated merchantable top d.o.b. are shown in table 1 for PST trees in the 12-17 inch d.b.h. classes. The lower d.b.h. value was chosen since that was the minimum d.b.h. for PST in the region where the product specifications called for an 8-inch d.o.b. top. The upper limit was set because there were insufficient trees in the larger d.b.h. classes to have a reasonable number of observations across all cells.

The ANOVA suggests that the only main effects that were significant were d.b.h. and stand origin. The effect of regions where the cruise specification for PST called for either a 6-inch or an 8-inch d.o.b. top was not significant. That suggests that merchantable height for 12-inch and larger PST is limited more by tree quality factors than the top d.o.b. specification. None of the interactions were significant.

Stand origin was significant at the five percent level, but differences in the mean top d.o.b. between planted and natural stands were only about 0.2 inch. This result would likely have been different if the top d.o.b. had been calculated using equations developed from each of these two stand types.

The effect of d.b.h. on top d.o.b. was highly significant ($P<0.01$). The average top d.o.b. increased about 0.4 inch with each one-inch increase in d.b.h. class.

Similar results occurred when the ANOVA was done with a wider range of d.b.h. classes, but restricted to the region where the top d.o.b. specification for both CNS and PST was 6.0 inches. The summary table for this analysis is shown in table 2.

Both of these analyses suggest that the top d.o.b. is driven by d.b.h. rather than the product specification for top d.o.b. That would imply merchantable height is limited more by tree quality factors than the product specification. These analyses also show that the effect of origin on top d.o.b. is small relative to the influence of d.b.h. Consequently it would seem that little error would be introduced by combining trees from both planted and natural stands when evaluating the effect of d.b.h. on top d.o.b.

The distribution of estimated top d.o.b. values by d.b.h. class is shown as a box and whisker graph in figure 1. The lower and upper horizontal lines of each box represent the 25th and 75th percentiles respectively. Each whisker represents one quarter of the percentile distribution. It can be seen that median values are close to the values defined by the product specification only for trees in the 8- and 9-inch-diameter classes. As d.b.h. increases beyond that value, so does the median value for top d.o.b. About 75 percent of the trees in the 11-inch class had a top d.o.b. greater than the spec top. This increased to 100 percent at the 15-inch d.b.h. class.

It should be clear from figure 1, that the top d.o.b. observed across a wide range of diameter classes is larger than the top d.o.b. called for by the product specification. It is clearly not a constant, but a variable whose value changes with d.b.h. Similar results have been reported elsewhere. Westfall (2006) showed that use of a taper equation to predict merchantable height to a fixed top d.o.b. overstated merchantable height, and the amount of overstatement increased with d.b.h.

The issue is how much additional chip-n-saw and sawtimber volume will be calculated for each d.b.h. class when that volume is calculated to a fixed top d.o.b. relative to the median values shown in figure 1. An Excel spreadsheet was developed to calculate the hypothetical diameter distribution and total height by d.b.h. class for a specified set of stand attributes. Equations used were those reported in Harrison and Borders (1996) for the lower coastal plain. That data was used to calculate merchantable tons to both a fixed 6-inch d.o.b. top and to the median top d.o.b. values of figure 1. For this example, the stand was assumed to be age 25, site 75, and stocked with 150 trees per acre.

Results are shown in figure 2. The overstatement, shown on the Y-axis, is the additional tons to a 6-inch d.o.b. top expressed

Table 1—ANOVA for DBH, origin, and spectop for pine sawtimer in the 12-17 inch diameter range

Source	DF	SS	MS	F	P	
DBH	5	745.45	149.09	76.2	0.001	***
Origin	1	12.65	12.64	6.5	0.011	*
SpecTop	1	0.94	1.94	1.5	0.220	NS
Dbh x Origin	5	1.00	0.38	0.2	0.966	NS
Dbh x SpecTop	5	1.88	2.60	1.3	0.249	NS
Origin x SpecTop	1	12.98	0.70	0.4	0.551	NS
Dbh x Origin x SpecTop	5	0.70	1.55	0.8	0.554	NS
Error	-	7.77	1.96	-	-	
Total	-	7705.12	-	-	-	

*** Differences due to dbh are 0.4+ inches for each dbh class.
* Differences due to origin are about 0.2 inch.

as a percentage of tons based on the median values of figure 1. The relationship between d.b.h. and volume overstatement depends upon whether all trees are considered, or only those whose calculated top d.o.b. was in the 6-inch class or larger. For this latter case, there is a more or less linear relationship between d.b.h. and volume overstatement. For the former case, volume overstatement increases sharply with d.b.h. to about the 12-inch class and more slowly thereafter.

Figure 2 implies that the average volume overstatement varies with d.b.h., is about the 2-9 percent range for CNS and 10-15 percent for PST through the 17-inch class. It is in the 15-20 percent range for trees whose d.b.h. is 18+ inches.

The trend shown in figure 2 is not strongly influenced by age or site quality. The percentage overstatement declines slightly as these attributes increase. The point to note is that specification of a single fixed top d.o.b. by product will likely result in volume overstatements that may not be trivial. More accurate estimates can only be obtained by allowing the top d.o.b. to vary with d.b.h.

An alternative way of expressing the top d.o.b. is to define it as a proportion of d.b.h. That definition will subsequently be referred to as top ratio. The relationship between top ratio and d.b.h. is shown is shown as a box and whisker graph in figure 3. As can be seen, top ratio declines rapidly with increases in d.b.h., but trend toward stability when d.b.h. is in the range of 12-13 inches and greater. At that point, median values are in the range of 0.55-0.60.

Top d.o.b. calculated as the product of median values of figure 3 and d.b.h. will result in the same median values shown in figure 1. The advantage of specifying top d.o.b. as a proportion of d.b.h. from a growth and yield standpoint is twofold. First, the calculated volumes will be closer to actual values on average, and second, the top d.o.b. for sawtimber size trees can be characterized with a single input variable.

Examination of figure 3 shows that there is considerable variability about the median values. For any one d.b.h. class, the top d.o.b. could be as low as 40 percent or as high as 90 percent of d.b.h. This variability is due to variation in the ratio of merchantable height divided by total height. That ratio will be referred to as height ratio in the remainder of this discussion. Another term, often found in the literature, is relative height.

Table 2—ANOVA for DBH and origin of pine cns and sawtimber in the 8-20 inch diameter range

Source	DF	SS	MS	F	P	
DBH	12	8131.60	677.60	493.8	0.017	*
Origin	1	10.60	10.60	7.7	0.006	***
Dbh x Origin	12	20.90	1.74	1.3	0.966	NS
Error	10109	13871.00	1.37	1.3	0.230	NS
Total	10134					

* Differences due to dbh are 0.4+ inches for each dbh class.
*** Differences due to origin are about 0.2 inch.

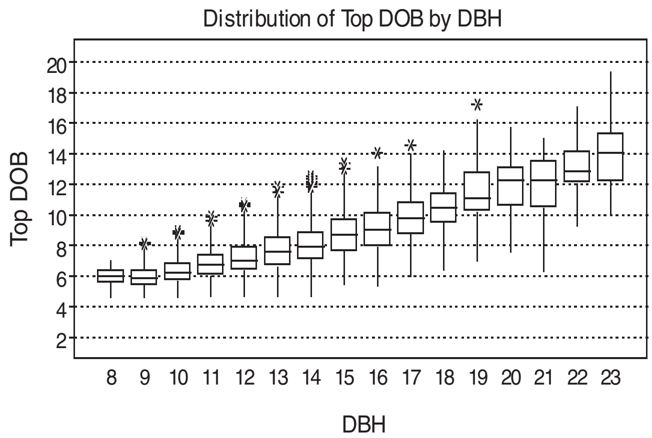

Figure 1—Variability in estimated top d.o.b. by d.b.h. class.

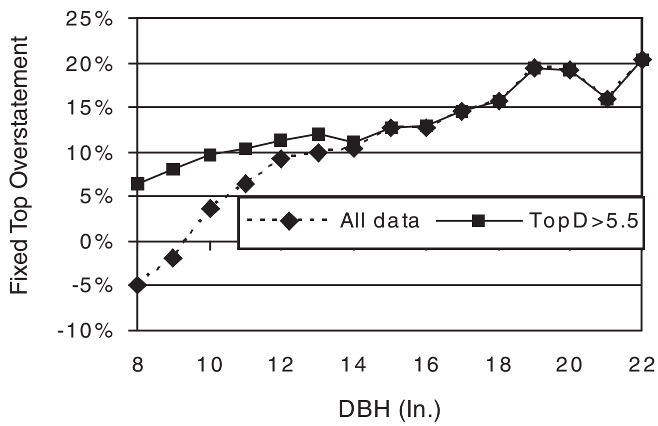

Figure 2—Volume overstatement due to assumption of a fixed 6-inch d.o.b. top.

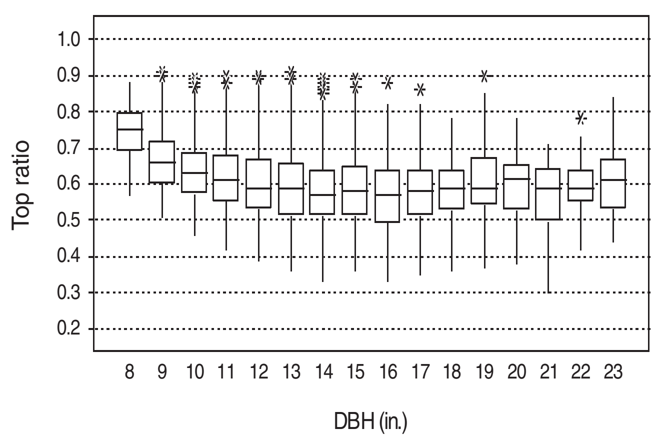

Figure 3—Top d.o.b. as a proportion of d.b.h.

There was nearly perfect correlation between diameter ratio and height ratio. That near-perfect relationship is an artifact of the analysis and would not have been near as good had actual top d.o.b. been available. It suggests however that height ratio is an important determinant of top d.o.b., and of the volume overstatement that could occur when a fixed top d.o.b. is assumed.

Volume overstatement was calculated using the individual tree data subset. The relationship between volume overstatement and both height ratio and merchantable height is shown in figure 4.

Volume overstatement at the tree level ranges from less than zero to almost 400 percent. Negative overstatements occur because the calculated top d.o.b. was less than 6.0 inches for some trees. Height ratios are in the range of 0.2 to a little over 0.8, and merchantable height ranges from 16 to almost 90 feet. Large overstatements are associated with small height ratios or trees whose merchantable height is short relative to their total height. Overstatements of 100 percent or more seem to be restricted to trees with 32 feet or less of merchantable height. However these trees may also have a negligible overstatement except for those trees with only 16 feet of merchantable height. Overstatements are small where height ratios are large or where trees have five to six logs of merchantable height.

Stand level

The tree level analysis discussed in the previous section has shown that the volume overstatement due to the assumption of a fixed top d.o.b. varies directly with d.b.h. Furthermore, since top d.o.b. is inversely related to merchantable height, volume overstatement varies inversely with height ratio. This section will show that the volume overstatement at the stand level for the various pine products is also inversely related to the average height ratio for each product.

The stand level analysis was done using about a 1,200 stand subset of the 3,000 cruised stand database. Stands in this subset were restricted to loblolly pine plantations cruised with a minimum of ten plots and occurring in areas where the product specification for both CNS and PST included a 6-inch d.o.b. top. Merchantable tons were worked up for each stand using both a 6-inch d.o.b. top, and a top d.o.b. implied by merchantable height. These two workup methodologies will be referred to a fixed top workup and a variable top workup respectively.

Data items calculated from this subset include volume overstatement as defined previously, height ratio by product, and a fixed top reduction factor. Product height ratio is the average height ratio calculated from all trees tallied as that product for each cruised stand. The fixed top reduction factor is the inverse of volume overstatement. It is simply a factor which when multiplied by a growth and yield estimate of product volume (fixed 6-inch d.o.b. top workup) will result in the volume calculated by a variable top workup.

Results are shown in figure 5 for PST on the left and for CNS on the right. Results for PPW are similar and won't be shown. It is clear from these two graphs that the relationship

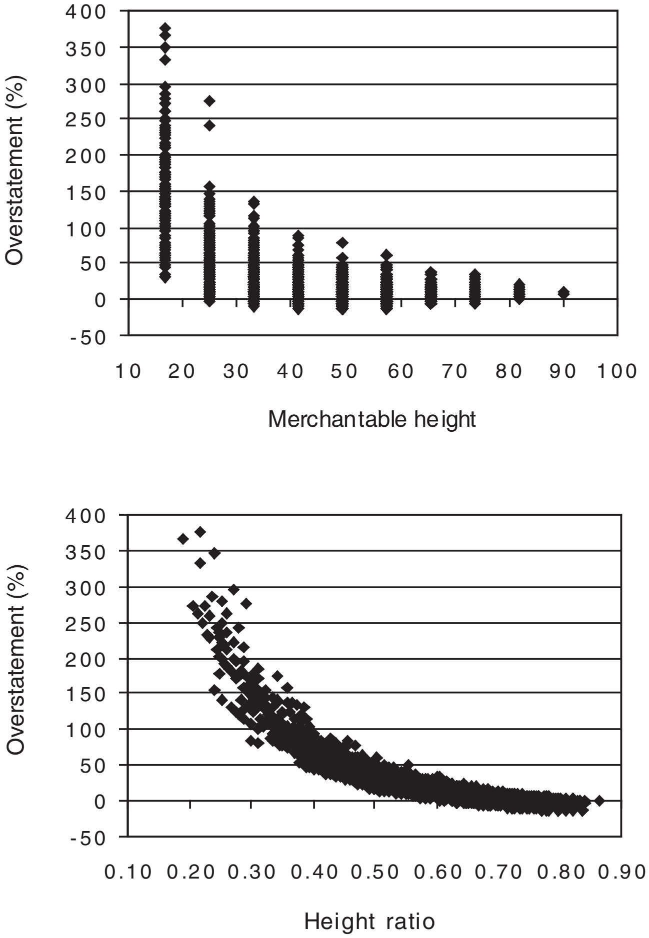

Figure 4—Overstatement as influenced by both height ratio and merchantable height.

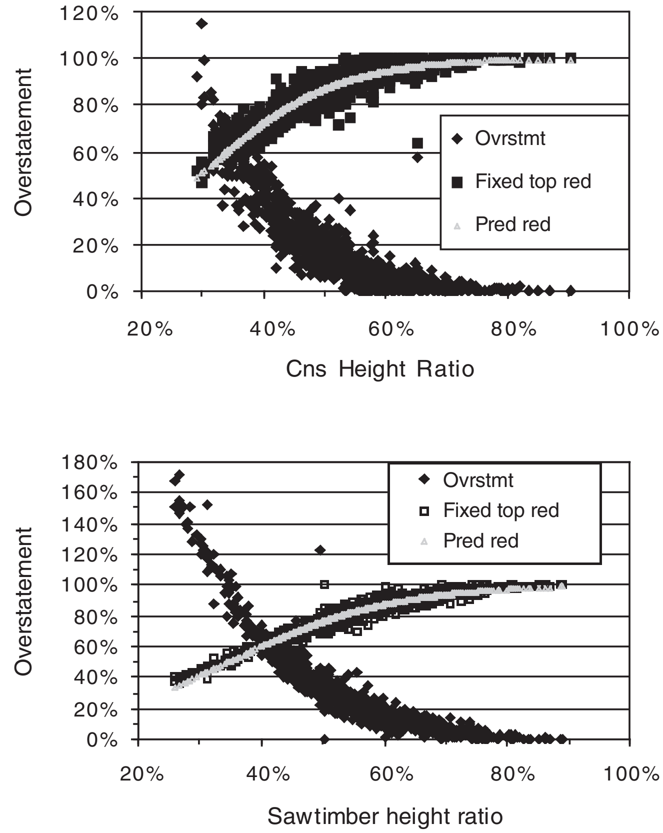

Figure 5—Overstatement, fixed top reduction, and predicted reductions related to average height ratio at the stand level for PST (left graph) and for CNS (right graph).

between average height ratio for a particular product at the stand level and volume overstatement of that product is similar to the relationship observed at the tree level (fig. 4).

Overstatements for PST range up to almost 170 percent, while overstatements for CNS range up to about 120 percent. The larger overstatements we re associated with stands containing less than five tons/acre of product. But a graph of all stands with less than five tons per acre of product does not appear to be different from the graphs shown in figure 5.

The growth and yield reduction factor is in the range of 0.4 to 1.0. As with volume overstatement, the reduction factor is inversely related to product height ratio.

Stepwise logistic regression was used to determine what stand variables were related to calculated values of growth and yield reduction factor for each product. The only variable having significance at the five percent level was height ratio. Predicted values show that product height ratios must be at least 60 percent or more in order for the volume reduction factor to be at least 0.9 when volume workups are to a fixed 6-inch d.o.b. top. Another way of stating that is that if product height ratios drop below 60 percent, then volume workups based on actual top d.o.b. will be around 90 percent or less of fixed top workups.

The distribution of actual and cumulate overstatement by product is shown in figure 6. These distributions are peaked and highly skewed to the right. Modal overstatements for PPW and CNS are about five percent. The modal overstatement for PST is about 16 percent. The median overstatement was about 8, 10 and 16 percent for PPW, CNS, and PST respectively. Overstatements at the 95th percentile were 30, 55, and 80 percent for these products respectively. This graph shows that estimates of higher-value products based on a fixed top workup assumption tend to be liberal, and that the amount of product overstatement increases with product value.

It should be noted that the results shown here are not based on field measurements of top d.o.b. and total height. Recall that top d.o.b. was estimated from a taper equation. In addition, total height was estimated from a diameter-total height equation where dominant height was one of the regressor variables. Dominant height in turn was seldom measured, but was estimated from different sources. While it could be argued that the results are simply an artifact of the analytical methodology, additional lines of evidence suggest that is unlikely.

Drs. Honorio Carino and David Smith of Auburn University have graciously provided a dataset of 160 trees from three loads of long wood delivered to a local wood yard. Variables measured for each tree in that dataset included d.b.h., merchantable length and top d.o.b. The stand level cruise dataset provided

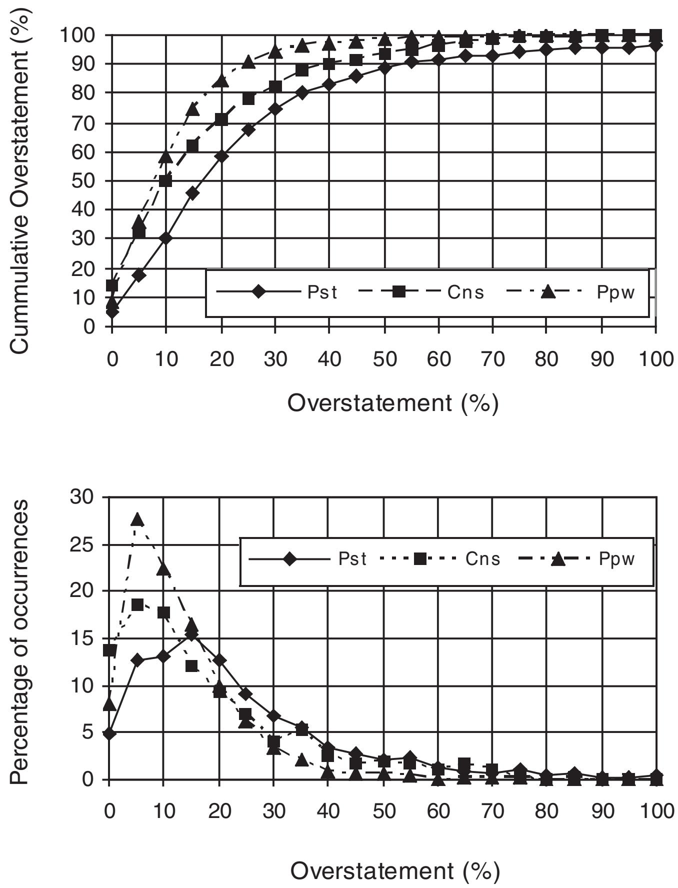

Figure 6—Distribution of overstatement: frequency on the left and cumulative on the right.

a second line of evidence. Top d.o.b. was estimated by the cruisers for many of the stands cruised. Finally, a property-level cruise in northcentral AL, where both merchantable and total height was estimated for each tree provided a third line of evidence. For this dataset, top d.o.b. was estimated with the same taper equation used for the stand-level cruise dataset.

Simple linear regressions predicting top d.o.b. from d.b.h. and merchantable height were done separately for each of these additional datasets. R-squared values were in the range of 0.80 to 0.85 except when the dependent variable was cruiser estimate of top d.o.b. For that case, it was around 0.50. A diameter range of 8-18 inches was specified, and merchantable height values, typical of those for each d.b.h. class were assumed. Top d.o.b. predicted by the equations derived from each dataset was plotted against D2H values. Results are shown in figure 7.

The direct measurements of top d.o.b. from the wood yard data resulted in diameters that were more than an inch larger than those from those predicted from the cruise data set. Top d.o.b. based on cruiser calls were slightly larger than those predicted from the cruise data set. Values from the northcentral AL data set were somewhat smaller. Timber stands in this latter dataset were all unthinned loblolly pine plantations, so excessive limbiness is less likely to limit merchant table height. Consequently such trees would likely have had a greater merchantable length and a correspondingly smaller top d.o.b. than the average tree in the cruise data set.

The point to note is that these additional data sets fail to provide evidence that the results are an artifact of the analytical methodology. If anything, they show that the results presented could be conservative.

Additional research involving the direct measurement of the top d.o.b. associated with merchantable height would server to either confirm or refute these results. Merchantable height is a somewhat subjective concept except for obvious factors such as forks or crooks. Input from experienced timber buyers would aid in the design of a study protocol.

Attempts to relate PST height ratio to stand attributes such as basal area, trees per acre, age, etc. or to geographic locality were largely unsuccessful. The best R-squared values using stepwise regression relating stand attributes to height ratio were only in the range of 0.15 to 0.20.

It may seem reasonable to believe that geographical areas where natural agents such glaze storms or fusiform rust are common would have lower height ratios than geographic areas where these risks are infrequent. When stands were grouped into classes representing these hazards, the F ratio for a one-way ANOVA was not significant at the 0.05 level.

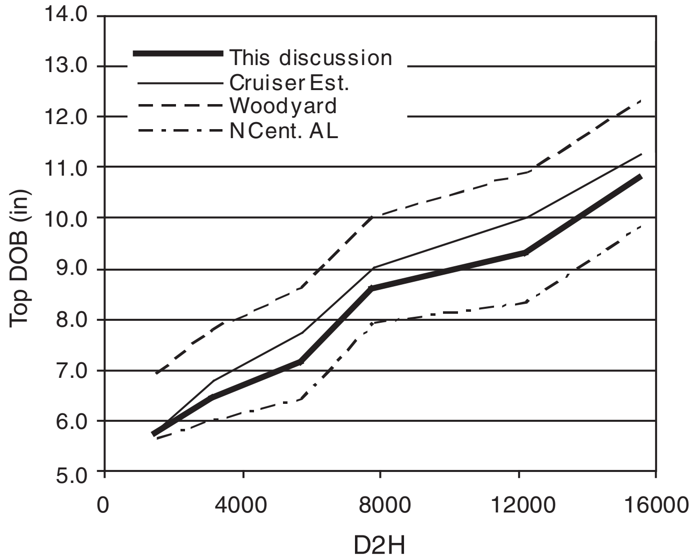

Figure 7—Comparison of top d.o.b. from this study with other data sources and methodologies.

There were significant differences among states or groups of states. Stands in eastern NC had significantly greater overstatements and significantly lower sawtimber height ratios than in other areas. For that region, PST overstatement averaged 30 percent and height ratio averaged 53 percent. But the differences in the mean values were not large, and there was considerable variability about them. When these stands were removed from the dataset, there were no significant differences in either PST overstatement or height ratio.

These results imply that abnormal PST height ratios can occur in any stand, but their occurrence cannot be predicted in advance of stand examination. Their influence on cruise estimates of product volume can be accounted for only by a data collection protocol and workup methodology that accounts for both total and merchantable height for those trees whose top d.o.b. is larger than the product specification.

It will be more difficult to incorporate merchantable height into growth and yield models. Little is known about how it varies with stand attributes or over time. Perhaps the best that can be done is to simply be cognizant that estimates may overstate product volumes by an amount that is not trivial.

Finally, financial analysis supporting low density management using growth and yield estimates of product values may overstate higher value product volume and value to the extent that the conclusions are questionable.

CONCLUSIONS

This analysis has shown that the merchantable top diameter for CNS and PST products is not the constant value associated with the product specifications. Instead it is a variable that is directly related to d.b.h. The assumption that it is a constant will commonly overstate product volume. In this study, volume workups to a fixed 6-inch d.o.b. top overstated CNS and PST volume by ten and sixteen percent respectively relative to variable top workups where top d.o.b. was implied from merchantable height. For PST in the 12-inch and larger d.b.h. classes, the estimated top d.o.b. averaged 55-60 percent of d.b.h. Modification of growth and yield systems to permit specification of top d.o.b. as a percentage of d.b.h. will reduce the overstatement for the average stand relative to what would occur when a fixed top d.o.b. is assumed across all d.b.h. classes. Product overstatement is also inversely related to height ratio or merchantable height divided by total height. Overstatement is small when height ratio is about 0.75 to 0.80 or greater. It can exceed 100 percent when height ratio for PST drops below 0.30 to 0.35. Differences in height ratio result in differences in top d.o.b.; trees with small height ratios have a large top d.o.b. Top d.o.b. can be in the range of 40 to 80 percent of d.b.h., depending upon height ratio. Top d.o.b. was not measured but estimated using equations developed for use with growth and yield models. While it could be argued that the results are an artifact of the analytical methodology, comparison with other datasets including direct measurements of logs in a wood yard suggest that they are realistic. Overstatements are at best weakly related to stand attributes or geographical locality. They can only be minimized from an inventory standpoint when estimates for both merchantable and total height are available for trees whose top d.o.b. is greater than the product specification.

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