Using double-sampling techniques to reduce the number of measurement trees during forest inventories

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Abstract

Variable-radius sampling techniques are commonly used during forest inventories. For each sample tree at a particular sampling point, diameter and height(s) are measured and then weight is estimated using established equations. Heights can require a fair amount of time to measure in the field. Separating the weight per acre estimate into two components; average basal area per acre and WBAR (individual tree weight-basal area ratio) across all points, can often lead to more efficient sampling schemes. Variable-radius sampling allows for a quick estimate of basal area per acre at a point since no individual tree measurements are needed. If there is a strong relationship between weight and basal area, then by knowing basal area you essentially know weight. Separation into two components is advantageous because in most cases there is more variability among basal area estimates per point then there is in WBAR. Hence, you can spend more resources establishing many points that only estimate basal area – often called “Count” points. “Full” points are those where individual tree measurements are also conducted. There is little published information quantifying the impacts on basal area, weight, etc., estimates among different “Full/Count” sample size ratios at the same site. Inventories were examined to determine this method’s applicability to loblolly pine plantations in southern Arkansas and northern Louisiana. Results show there is more variability among basal area estimates than WBAR and that the amount of trees being “intensively” measured is excessive. Based on these four plantations, a “Full” point could be installed ranging from every other point to every fifth point depending on site conditions and the desired variable.

Keywords

Basal Area; Loblolly pine; *Pinus taeda*; VBAR; WBAR

Contents

1 Introduction

Forest inventories are used to estimate the resources that exist on a site and aim to balance both accuracy and precision while minimizing time and cost. Variable-radius sampling techniques are commonly used in the southeastern US. A 20 Basal Area Factor (BAF) is used regularly to select sample trees where each sample tree represents 20 square feet of basal area per acre (4.6 sq m ha^{-1}). For each sample tree, diameter and height(s) are measured and then volume, weight, biomass, etc., are estimated using equations. Diameter and especially height, can require extensive time for field measurement.

Techniques to increase temporal sampling efficiency can allow the forester to make more accurate measurements since sample sizes will be reduced and/or can reduce the amount of time required to sample. This can lead to one of two outcomes when comparing either result to "traditional" inventory procedures – reductions in sampling time while still achieving the same level of statistical precision or producing an increase in statistical precision since sample sizes can be increased for the same level of cost (Coble and Grogan 2007).

One common way to estimate average tons per acre is to use equation [1]:

$$\overline{T}=\overline{TC} * \overline{WBAR} \qquad [1]$$

Where: $\overline{T}$ - average tons per acre/ha, $\overline{TC}$ - average tree count per point (or sampling unit) multiplied by BAF, and $\overline{WBAR}$ - average weight-basal area ratio.

This approach separates the estimate into two components, an average number of sample trees per point (or sampling unit) and an average ton per tree measurement across all points. Often the term "tree count" is used to refer to the number of sample trees at a particular point and WBAR (Weight-Basal Area Ratio) is used to refer to the weight per tree. Separating the estimate into two components is advantageous because in most cases there is more variability among the number of sample trees per point then there is in WBAR. Yet, variable-radius techniques provide a very low cost method to estimate the number of count trees per point since basal area at a point can be estimated without the need to measure diameter or heights.

If there is a strong relationship between weight and basal area, then by knowing basal area you essentially know weight (or volume, biomass, etc). Hence, you can spend more resources establishing many points to estimate basal area within a forested stand while measuring a reduced number of the more time costly diameter, height, and weight measurements while still achieving the same level of precision or perhaps even producing a greater level of precision at the same level of cost.

One approach (Fig. 1) to take advantage of this sampling technique is to install many "Count" points where only basal area is measured and a reduced number of "Full" points where both basal area and tree measurements are conducted (Shiver and Borders [1996, pgs. 212-218]; Avery and Burkhart [2002, pgs. 250-252]). This method is further referred to as "double-sampling." This sampling protocol was recognized as useful (e.g. Bell and Alexander 1957) almost as soon as variable-radius sampling was introduced into the United States. If there is a strong correlation between basal area and weight, or low variability in the $\overline{WBAR}$, then establishing many "Count" points will allow the forester to measure more of the population while still getting a good estimate of weight. Conceptually at least, measuring more of the population will produce a better estimate.

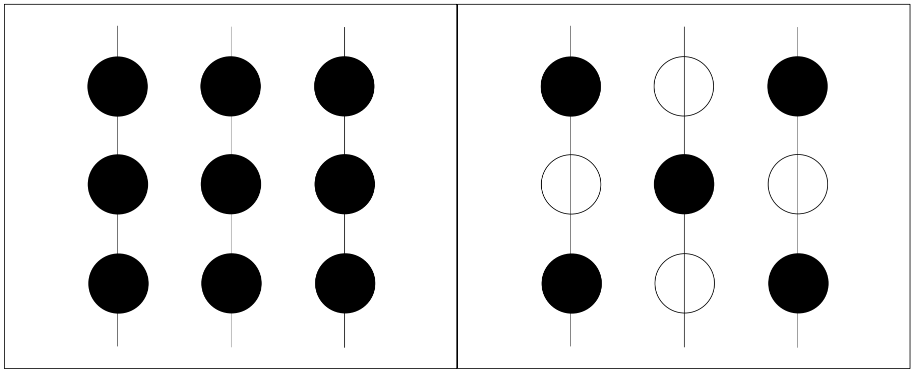

Figure 1. Example of a potential grid layout of plots/points where full circles are "Full" plots/points and open circles are "Count" plots/points. When using a "traditional" approach all nine plots/points would be "Full" plots/points (on the left) – or basal area would be estimated and then height, diameter, form, etc., would be measured on all sample trees and then volume, biomass, etc., would be estimated using equations. Under a double-sampling approach (right) for this example every other plot/point would be a "Full" plot/point. For the open circles only basal area would be estimated.

Often the "Full" points are located systematically, such as every other point, or every third, etc. Avery and Burkhart (2002, pg. 252) state that every fourth or fifth point can be a "Full" point while Shiver and Borders (1996, pg. 216) basically make the same statement since they recommend that no more than 25% to 35% of the "Count" points need to be "Full" points. However, the ratio between "Count" and "Full" points will likely need to vary among forest types and probably even among ages and different management regimes of the same forest type.

Coble and Grogan (2007) compared the relative sampling efficiencies of double-sampling to "traditional" inventories where all points were "Full" points in East Texas pine plantations. Two categories of "Mature" and "Young" were each inventoried using 10 separate plantations for a total sample size of 20. However, the ratio between "Full" and "Count" points was fixed at a 3:1 ratio based on work from the Pacific Northwest. Hence, different "Full/Count" ratios were not compared at a particular site. For "Mature" and "Young" plantations they found that double-sampling was more time and cost efficient in 7 and 4 of the 10 plantations, respectively.

Often sample size and optimum ratios between "Full" and "Count" points are based on volume or weight estimates. However, it can be somewhat confusing determining whether total volume/weight or some merchantable product class volume/weight should be used. Appraisals are more comprehensive because the value is based on all merchantable timber product classes.

Cochran (1960) and Oderwald and Jones (1992) present sample size estimates of "Full" and "Count" points needed to meet some level of precision based on the relative cost of establishing the two types of sample points. Although useful, an individual must estimate the relative costs among the two types of sample points. This in some cases can be difficult. Another approach is to use inventory data from similar stand conditions as the stand currently being inventoried to infer about the optimum ratio between "Full" and "Count" points. For inventories where every point was "Full," an individual can simulate inventories using a "double-sampling" approach by treating a reduced portion of the "Full" points as merely "Count" points. This is a much more direct approach at examining how various Full/Count ratios impact volume/weight/appraisal estimates.

Although double-sampling is currently utilized by foresters to some degree, there is little published information quantifying the impacts on basal area, weight, appraisal, etc., estimates among different double-sampling “Full/Count” sample size ratios at the same plantation. This is particularly true for appraisal values and for loblolly pine (*Pinus taeda* L.) plantations. To determine the applicability of this sampling method to loblolly pine plantations in the Western Gulf region, inventories of plantations in southern Arkansas and northern Louisiana were examined.

2 Methods

Two operationally established plantations in northern Louisiana and two operationally established plantations in southeastern Arkansas were examined (Table 1). All plantations except for the Arkansas Two site were inventoried using “traditional” methods where diameters and heights were measured (i.e., Full points) on all sample trees to estimate weights. For the Arkansas Two site, a double-sampling approach of every third point being a “Full” point was originally employed. Hence, for this study, the original sampling scheme was compared to taking half of the original “Full” points, resulting in two separate estimates of essentially a “Full” point every fifth point. Inventories were conducted by students during summer field inventory courses and a BAF of 20 was used at all four sites. All plantations were basically pure loblolly pine. Hence, these results will not necessarily apply to plantations that contain a fair amount of basal area, weight, or volume, etc., of other species.

Table 1. Stand-level summary statistics of the plantations. Where: SI – site index (base age 25) in ft/m, TPA/TPH – trees per acre/ha, BAA/BAH – basal area per acre (ft^2)/basal area per ha (m^2), QMD – quadratic mean diameter (inches/cm), and TAA/TAH – green megagrams per acre/ha.

Plantation	State	SI (ft/m)	Number of points	Number of "Full" trees	TPA/TPH	BAA/BAH	QMD (inches/cm)	TAA/TAH
One	AR	62/19	20	79	175/71	79/18.1	9.1/23.1	53.0/21.4
Two		59/18	20	29	85/34	83/19.1	13.3/33.8	72.5/29.3
Three	LA	57/17	20	61	33/13	61/14.0	17.5/44.5	63.0/25.5
Four		58/18	18	92	60/24	102/23.5	17.7/45.0	112.6/45.6

Since all points were obtained using a “traditional” approach where all are “Full” points, to see the efficiency of “double-sampling” we assumed a reduced number of the original “Full” points were only “Count” points. Hence, at these points other than tree counts all other tree measurements were ignored. If sample sizes at a particular plantation allowed, up to using only every sixth point as a “Full” point was examined. For example, if the “traditional” inventory approach originally consisted of 15 “Full” points, then to test whether every third point using a double-sampling scheme produced similar weight and stumpage value estimates, point One was treated as a “Full” point. Points Two and Three were then considered only “Count” points. The fourth, seventh, tenth, and thirteenth points would also be considered as “Full” points, and points five and six were considered only “Count” points, etc. For purposes of testing, every plot was measured as a "Full" point in the field (except for the Arkansas Two site where only half were originally measured as “Full” points), but in the "Count" points for the double-sampling scheme the specific measurements were ignored. Average tons per acre was then estimated using equation [1].

All potential combinations for a particular sampling scheme (e.g. every fourth point as a “Full” point) were examined. For instance, rather than using points 1, 4, 7, 10, and 13 in the example above as “Full” points, points 2, 5, 8, 11, and 14 could be used as “Full” points. Only those combinations of “Full” and “Count” points where sample size was constant for a particular ratio were used.

To examine the impacts of double-sampling on economic values, timber appraisals were conducted based on the inventory data. For simplicity, a constant stumpage value for a particular product was used based in part on actual current stumpage values. See Table 2 for the specifications that were used during the inventories.

Table 2. Minimum and maximum diameter at breast height and upper-stem diameter outside bark (DOB) wood product specifications used during inventories and stumpage values.

Arkansas

	DBH (inches/cm)			
Product	Minimum	Maximum	Upper Stem DOB (inches/cm)	Stumpage Value Per Mg
Pulpwood	4/10.2	-	2/5.1	$9.99
Chip-n-saw	9/22.9	12/30.5	4/10.2	$14.31
Sawtimber	12/30.5	-	8/20.3	$28.07

Louisiana

	DBH (inches/cm)			
Product	Minimum	Maximum	Upper Stem DOB (inches/cm)	Stumpage Value Per Mg
Pulpwood	4.5/11.4	-	2/5.1	$9.99
Chip-n-saw	8/20.3	11/27.9	410.2	$14.31
Sawtimber	12/30.5	-	6/15.2	$28.07

3 Results and Discussion

Table 3 and Figures 2, 3, 4 show there is more variability among basal area estimates than WBAR. Clearly the amount of trees being “intensively” measured exceeds the required amount. For WBAR sample sizes of around 45, 15, 25, and 25 individual trees for sites Arkansas One, Arkansas Two, Louisiana Three, and Louisiana Four, respectively, seem reasonable for a particular site’s most valuable merchantable product class. Of course each forester is going to differ as to what would be satisfactory. Based on the average counts on these sites, this would equate to installation of a “Full” point every other, fifth/sixth, other/third, and third/fourth point, respectively.

Table 3. Mean, standard deviation (St Dev), and coefficient of variation (CV%) of basal area and total merchantable Weight-Basal Area Ratio (WBAR) estimates.

				Basal Area Per Acre/Ha			**WBAR - Total**		
Plantation	State	Number of points	Number of "Full" trees	Mean	St Dev	CV%	Mean	St Dev	CV%
One	AR	20	79	79/18.1	27.9/6.4	35%	0.670	0.040	6%
Two		20	29	83/19.1	38.5/8.8	46%	0.874	0.059	7%
Three	LA	20	61	61/14.0	22.9/5.3	38%	0.547	0.165	30%
Four		18	92	102.3/23.5	20.5/4.7	20%	1.101	0.096	9%

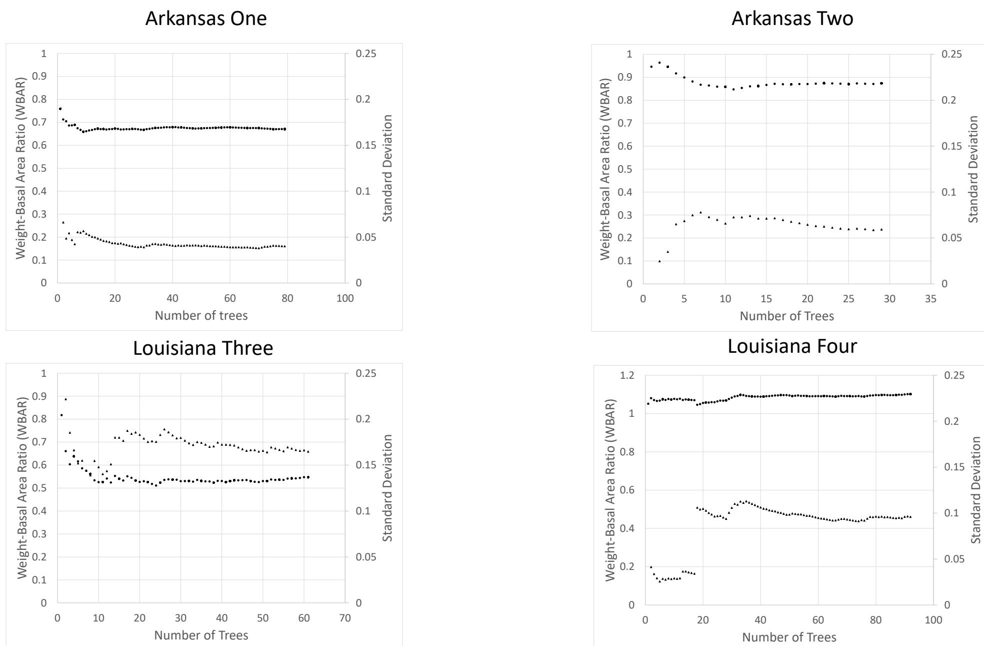

Figure 2. Running mean of the Weight-Basal Area Relationship (WBAR) of individual trees as additional "Full" points are measured. Weight is total merchantable weight. Black circles are "running" means and black triangles are "running" standard deviations.

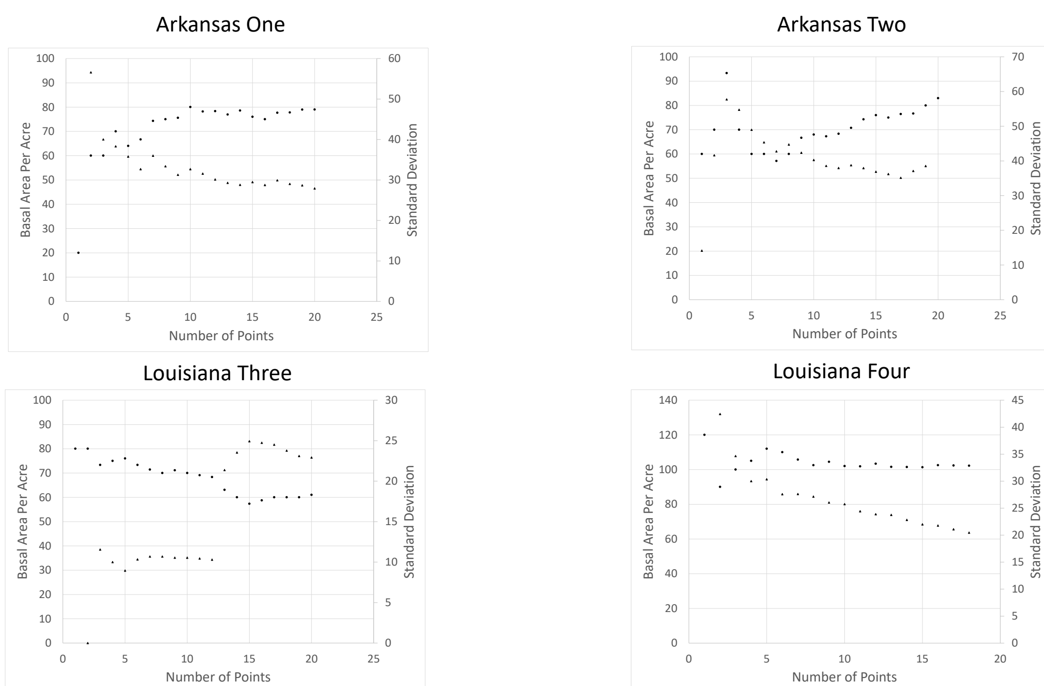

Figure 3. Running mean of basal area per acre estimates as additional points are measured. Black circles are "running" means and black triangles are "running" standard deviations. One square m of basal area per ha equals 4.36 square ft/acre.

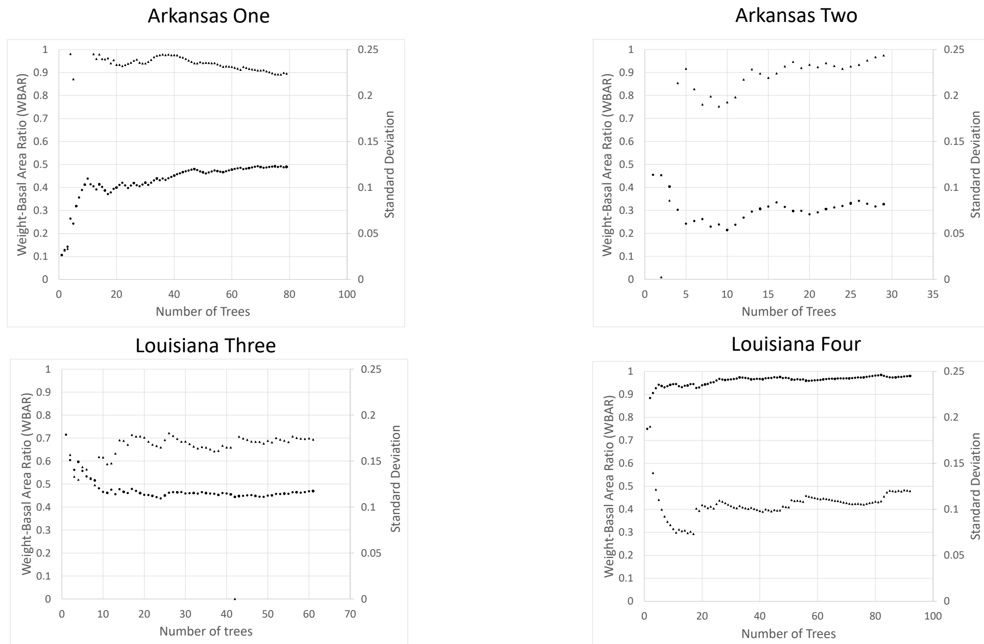

Figure 4. Running mean of the Weight-Basal Area Relationship (WBAR) of individual trees as additional “Full” points are measured. Weight is merchantable sawlog weight for Arkansas Two, Louisiana Three, and Louisiana Four but is merchantable pulpwood weight for Arkansas One since pulpwood is the most valuable product class on that site. For Arkansas One pulpwood is for both trees allocated only to pulpwood and those trees that have only upper-stem pulpwood (or topwood). The inclusion of upper-stem pulpwood adds substantial variability. Black circles are “running” means and black triangles are “running” standard deviations.

For instance on site Arkansas One 79 trees were “intensively” measured on 20 “Full” points producing an average of 3.95 trees per point. Thus, if 45 trees need to be measured this would be around 11.4 points (45/3.95) which is roughly half of the 20 “Full” points. However, the pulpwood product class $\overline{WBAR}$ running mean for this site includes trees not only allocated exclusively to the pulpwood class but also those chip-n-saw and sawlog trees that have upper-stem pulpwood (or topwood). The inclusion of upper-stem pulpwood in calculating $\overline{WBAR}$ adds substantial variability (Table 4). Once again the estimates of what sample size should be used are certainly subjective and are likely somewhat conservative. These findings are consistent with recommendations in Avery and Burkhart (2002, pg. 252) and Shiver and Borders (1996, pg. 216).

Within the past 20 years many plantations have been established using relatively intensive practices such as clonal stock, genetically-improved seed sources, intensive site preparation, fertilization, etc., that should produce even more uniform plantations. In these plantations every third point would certainly be applicable. Both Arkansas plantations were at least 15 years old when inventoried and both Louisiana plantations were at least 30 years old. Given the low variability among WBARs within these plantations, certainly younger plantations should have similar and likely even lower variability among WBARs and hence every fourth and perhaps every fifth point would be applicable.

Table 4. Correlations between individual tree basal area and merchantable volumes. Mean is the average WBAR. *For Arkansas One the correlation coefficient is for pulpwood and not sawlog since it is the most valuable product class – this pulpwood coefficient is not only for those trees exclusively merchandized as pulpwood but also for chip-n-saw and sawlog trees that have upper-stem pulpwood (or topwood). **However, for only pulpwood trees, or where the entire tree is merchandized as pulpwood exclusively, the correlation coefficient is 0.969 and the Mean is 0.6598.

				Total		**Sawlog (Pulpwood for Arkansas One)**	
Plantation	State	Number of points	Number of "Full" trees	Mean	*r*	Mean	*r*
One	AR	20	79	0.6703	0.982	0.4897*	0.073*
Two		20	29	0.8735	0.982	0.3268	0.446
Three	LA	20	61	0.5470	0.397	0.4695	0.079
Four		18	92	1.1014	0.979	0.9792	0.945

Of course forest management will also impact the variability in average WBAR. Many agencies, particularly public agencies and perhaps some non-industrial private landowners, now are utilizing practices such as variable-density plantings/thinnings where to visually portray less uniformity in tree spacing the number of trees removed within pockets of stands varies. This variable-density will of course produce more variability in total and merchantable heights and therefore ultimately WBARs since different pockets will have different levels of competition that will impact self-pruning, taper rates of the stem, etc., that will produce variability in predicted total and merchantable weights per square foot of basal area.

Product class merchantable weight is more variable than total merchantable weight (Figures 2 and 4). This is to be expected, particularly for sawlog weight. Merchantable height is much more variable due to factors such as minimum stem diameter requirements, stem form (e.g. sweep), tree forks, branch angles, presence of excessive branching, etc. However, every third point is still likely applicable.

For management plans, where an inventory is being conducted only to get some idea of the resource existing on a site for planning into the future, every third or fourth point would clearly be sufficient and likely every fifth point could be established in relatively pure pine plantations. For timber appraisals, where inventories are being conducted to establish timber sales and hence financial transactions are directly dependent on the results, likely every fourth and perhaps every fifth point could be used, but more conservative foresters may want to use every third point as a “Full” point.

3.1 Stumpage Revenues

When looking at appraisal values within a site, estimated stumpage revenues per acre are fairly constant (Table 5). Once again, what amount of error or variability is considered acceptable will vary among foresters. Certainly the level of acceptability will differ whether inventorying for management purposes or appraisal purposes. In our opinion, for management purposes, all percent differences are acceptable given savings in time and money. However, for appraisals some of the percent differences may be high.

Table 5. Estimated stumpage revenues by plantation across different combinations of selecting "Full" points by double-sampling sample size.

	AR								LA							
	One				Two				Three				Four			
	BAA/ BAH	TAA/ TAH	$/Acre	% Diff	BAA/ BAH	TAA/ TAH	$/Acre	% Diff	BAA/ BAH	TAA/ TAH	$/Acre	% Diff	BAA/ BAH	TAA/ TAH	$/Acre	% Diff
All		53/131	$595.89	-		-	-			63/156	$1,603.75	-		113/278	$2,908.89	-
Every 2nd																
1		52/129	579.89	-2.7%						63/155	1608.29	0.3%		111/273	2849.65	-2.0%
2		54/133	608.61	2.1%						63/156	1599.64	-0.3%		115/284	2973.51	2.2%
Every 3rd																
1		53/132	600.23	0.7%		85/210	$1,235.02	-		62/154	1615.36	0.7%		111/274	2856.37	-1.8%
2		53/130	593.39	-0.4%						64/158	1612.42	0.5%		112/277	2842.18	-2.3%
3														116/286	3002.80	3.2%
Every 4th																
1		54/133	621.58	4.3%						63/156	1652.97	3.1%		112/277	2876.54	-1.1%
2		54/134	630.97	5.9%						62/154	1544.43	-3.7%		117/289	2957.57	1.7%
3	79/	51/125	544.78	-8.6%	83/				61/	62/152	1553.30	-3.1%	102/			
4	18.1	53/131	581.78	-2.4%	19.1				14.0	64/158	1642.58	2.4%	23.5			
Every 5th																
1		54/134	632.79	6.2%		91/225	1379.55	11.7%						118/293	3012.86	3.6%
2		52/128	567.6	-4.7%		83/205	1130.90	-8.4%						110/271	2775.13	-4.6%
3		51/127	574.93	-3.5%										112/277	2917.38	0.3%
Every 6th																
1		52/128	591.15	-0.8%										107/265	2803.02	-3.6%
2		53/132	614.83	3.2%										112/277	2880.93	-1.0%
3														112/277	2922.89	0.5%
4														112/277	2928.75	0.7%
5														112/277	2814.83	-3.2%
6														120/296	3087.71	6.1%

Using every third point as a "Full" certainly seems to produce reasonable percent differences within a site among different estimates even for appraisal purposes. Every fourth point as a "Full" at site Arkansas One may be unacceptable to some. A percent difference of 8.6% is fairly high. However, percent differences at sites Louisiana Three and Louisiana Four seem reasonable. Errors for every fifth point as a "Full" at sites Arkansas One and Arkansas Two seem high, but at site Louisiana Four error rates may be acceptable for appraisals by some.

As with any sampling the true value is never known. All conclusions about sampling error is based on probability. For example, at site Louisiana Four using every sixth point as a "Full" actually reduces error in most cases as compared to using every fifth – that is the nature of sampling error.

The State of Florida in their Timber Cruise/Timber Appraisal (TCTA) Standards document (http://www.dep.state.fl.us/lands/files/timber_cruise_manual.pdf) states that timber appraisals of Merchantable Planted Pine Timber conducted on state lands must be within +/-10% of the true volume at the 95% confidence limit. Coble and Grogan (2007) used a percent error of +/-15% for volume when calculating sample sizes. When assuming that the "traditional" inventories where all points were "Full" are considered the true value, almost all economic estimates using double-sampling techniques were within 10% (excluding site Arkansas Two where one was 11.7%).

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