A Comparison of Sample Unit Designs in the National Inventory of the U.S.

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Abstract.—The Forest Inventory and Analysis (FIA) program of the USDA Forest Service has adopted a new sampling unit for the national forest inventory of the U.S. We compared this new sampling unit with five other sampling units. Data from natural loblolly pine (*Pinus taeda* L.) stands in the Georgia piedmont show that all sample units produce reasonable estimates for the pine overstory in this stand type. However, plot clusters typically used by FIA to sample trees in the 1.0 to 4.9 inch dbh range can produce seriously biased estimates. Use of a single, subjectively chosen "site" tree, as done by FIA field crews, results in serious overestimation of site index for this stand type.

The Forest Inventory and Analysis (FIA) program of the USDA Forest Service is implementing significant procedural changes in various regions of the U.S.; e.g., the Annual Forest Inventory System (AFIS) in the lake states region, and the Southern Annual Forest Inventory System (SAFIS) in the southern region. These annual inventory systems have been adopted to improve the quality and timeliness of standing forest inventory data. Essentially, these annual inventory systems subsample a proportion of permanent ground locations each year and update the remaining permanent ground locations with some type of model or other updating procedure. One of the changes that was adopted along with these annual inventories is the use of a new sample unit design at each permanent ground location. FIA has used several different types of sampling units throughout the past 40 plus years: (1) a single fixed-area circular plot; (2) a single 10-BAF point; (3) a cluster of ten 37.5-BAF points for large diameter trees (dbh >= 5.0 inch) and ten 1/300-acre plots for small diameter trees (dbh from 1.0 to 4.9 inches); and (4) a cluster of five 37.5-BAF points for large diameter trees and five 1/300-acre plots for small diameter trees. The newest ground-based sample unit is a cluster of four 1/24-acre sample plots for large diameter trees and four 1/300-acre sample plots for small diameter trees.

Choice of sampling unit could have a large impact on resulting sample estimates for a given forest inventory. In fact, it is possible, indeed very probable, to carry out an inventory using different types of sampling units at the same exact ground locations and obtain different estimates of population parameters. This difference may be quite small or it may be very large depending on the specific population elements that are included in each sampling unit.

We conducted a field study to evaluate the utility of six different sampling units for characterizing natural loblolly pine (*Pinus taeda* L.) stands in the Georgia piedmont.

STUDY AREA AND FIELD METHODS

Bishop F. Grant Memorial Forest is located in the Georgia piedmont in Putnam County. This forest, owned and managed by the Daniel B. Warnell School of Forest Resources of the University of Georgia, is approximately 10,000 acres in size and contains a host of stand types ranging from hardwood bottoms to intensively managed loblolly pine plantations. For the study described in this paper, we sampled natural loblolly pine stands ranging in age from 20 to 80 years old. These stands are characterized by a pine overstory with a relatively small hardwood component in the understory.

To evaluate how various sampling units represent a given population, population parameters must be known. This is possible when simulation studies are done; however, when working with real world stand data, it is very difficult, if not impossible, to know population parameters. To overcome this problem we established a series of 49 square plots, each approximately 1-1/2 acres in size, as our "population." Each plot was 260 feet square so that all sampling units could be contained within the plot. On each plot, all trees were measured for dbh to the nearest 0.1 inch using a diameter tape, classified according to their crown position (dominant, codominant, intermediate, suppressed), and evaluated for the presence of fusiform rust (*Cronartium fusiforme* Hedge. And Hunt ex Cumm.). Furthermore, the total height of the first tree and every fourth tree thereafter in each 1-inch dbh class was measured to the nearest foot with a hypsometer. The

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number of 16-foot logs was estimated to the nearest one-half log for each pine tree large enough to contain at least one log. A subset of dominant and codominant trees were cored for age at 1 foot and at 4.5 feet from ground level.

Six different sampling units were established in the interior of each of the 49 large plots. The sampling units were (1) cluster of five 37.5-BAF sample points (fig. 1) as used by the USDA Forest Service[1] ; (2) a single 7.5-BAF

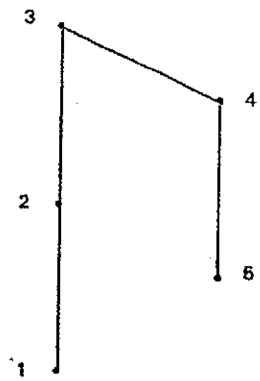

Figure 1.—*Layout of five-point cluster sampling unit. At each point a 37.5-BAF prism is used to select sample trees 5.0 inches dbh and larger. In addition, a 1/300-acre fixed-area sample plot centered at each point is used to select sample trees 1.0 to 4.9 inches dbh. Note—distance from point to point is 70 feet. The azimuth from point 1 to 2 and from 2 to 3 is 0 degrees, the azimuth from point 3 to 4 is 120 degrees, and the azimuth from point 4 to 5 is 180 degrees.*

sample point located at the center of the large plot; (3) cluster of four 1/24-acre sample plots (fig. 2) as used by the Forest Service; (4) a single 1/6-acre circular sample plot located at the center of the large plot; (5) a single 1/10-acre circular sample plot located at the center of the large plot; and (6) a single 1/20-acre circular sample plot located at the center of the large plot. At each point of the five-point cluster, a 37.5-BAF selection criterion was used to select trees 5.0 inches dbh and larger. Additionally, a 1/300-acre circular sample plot, centered at each of the five points, was used to select trees ranging in dbh from 1.0 to 4.9 inches. On each 1/24-acre circular sample plot of the four-plot cluster, trees 5.0 inches dbh and larger were sampled. Additionally, at the center of each of these 1/24-acre sample plots, a 1/300-acre circular sample plot was used to select trees ranging in dbh from 1.0 to 4.9

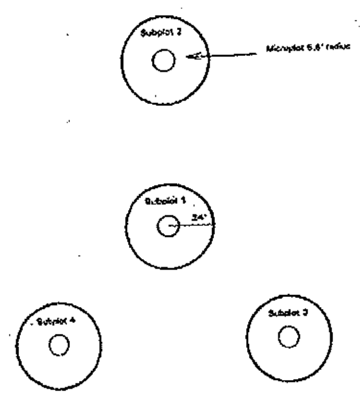

Figure 2.—*Layout of four-plot cluster. On each 1/24-acre subplot, all trees 5.0 inches dbh and larger are selected as sample trees. At the center of each subplot, a 1/300-acre microplot is used to select sample trees between 1.0 and 4.9 inches dbh. Note—distance from subplot center to subplot center is 120 feet. The azimuth from subplot 1 to 2 is 0 degrees, the azimuth from subplot 1 to subplot 3 is 120 degrees, and the azimuth from subplot 1 to subplot 4 is 240 degrees.*

inches. On the four other sample units listed above, all selected trees were included regardless of dbh. Note that the 1/6-acre circular sample plot was chosen because this is the same area sampled by the cluster of four 1/24-acre sample plots. The single 7.5-BAF point was used because it corresponds to the same sampling intensity as the cluster of five 37.5-BAF points. The 1/10- and 1/20-acre plots were used to evaluate the usefulness of smaller fixed-area sampling units. Note: all trees selected on each of the sampling units were measured for dbh to the nearest 0.1 inch with a diameter tape, classified as to crown position, and evaluated for the presence of fusiform rust. Additionally, total heights were subsampled and number of 16-foot logs to the nearest half log were estimated as described above.

DATA SUMMARIZATION AND ANALYSIS

All data for each large sample plot as well as for the six sample units were summarized for pine and hardwood separately as well as for both species groups combined for trees per acre (TPA), basal area per acre in square feet (BA), total volume per acre in cubic feet (VOL), and proportion of pine with fusiforme rust (R). Scribner (SCRIB) board foot volume was calculated for pine trees having one or more logs, using the equations developed by Wiant and Castaneda (1978). Additionally, average site index for each large plot was calculated using the function by Martin (1998) with all dominant and codominant trees that were measured for height and age at 1 foot from ground level. Site index on the cluster of five points and for the cluster of four fixed-area plots was calculated

[1] USDA Forest Service. Field instructions for the seventh forest inventory of Georgia. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Research Station. 146 p. Unpublished Draft.

using the height and age of a single dominant or codominant tree chosen by the field crew as being representative of the other dominant and codominant trees in the stand. This method was used to simulate the field procedures on FIA sample plots. Site index was also estimated for each of the sampling units using all dominant and codominant trees that were measured for height and age on the sampling unit.

Separate height—dbh models were developed for each of the 49 large plots. These models were used to estimate height for those trees not measured for height in the field. Cubic foot volume equations for natural loblolly pine were taken from Clarke and Saucier (1990) and for the hardwood species from Clarke *et al.* (1986). Note that separate estimates of each characteristic were obtained for trees from 1.0 to 4.9 inches dbh and for trees 5.0 inches dbh and larger to avoid the difficulties of combining estimates from the different types of sampling units used to select trees in these two size classes in the point and plot clusters. Of course, this difficulty does not exist for the sampling units that consist of a single point or fixed-area plot for which all trees were selected without regard to dbh.

All of the large 260-foot square plots were combined to establish our hypothetical population. For each stand measure described above, the population parameter was obtained using the 100 percent census of these 49 plots. For each of the six different sampling units, each stand measure was estimated using the trees selected and measured on the sampling unit. Note that the height—dbh regressions fitted to the large plot were used to estimate heights for trees that were not measured for height on each of the sampling units within each large plot. This was done to avoid confounding the analysis with height—dbh relationships that were not equally well established. The estimates obtained for each sampling unit were averaged across the 49 plots as if they represented a random sample of sampling units from the population. For each stand parameter, the estimate, standard error, and 95 percent confidence interval were calculated and compared with the population value.

RESULTS

Population values and sample estimates for each sample unit for TPA, BA, VOL, R, and SCRIB for the pine component greater than 5.0 inches dbh for these natural loblolly pine stands show that all sampling units provide sample estimates relatively close to the population parameter (tables 1-5). In fact, all sampling units produce 95 percent confidence intervals that contain the population parameter for all of these stand characteristics except the estimates from the 1/20-acre sampling unit. The variability of the estimates is smaller for the 1/6-acre plot compared with the cluster of four 1/24-acre plots, as well as smaller for the 7.5-BAF point than for the cluster of five 37.5-BAF points. This should be expected since the clusters sample a larger area than the single plot or point. The variability of the single 1/10-acre plot was smaller than or only slightly larger than the variability associated with the cluster of 1/24-acre plots. Clearly, estimates from the single 1/20-acre plot had a great deal more variability associated with them than estimates from all other sampling units.

The hardwood understory in these stands is patchy and consequently highly variable. Estimates of the average TPA and BA for hardwood trees from 1.0 to 4.9 inches dbh indicate that the 1/6-acre, 1/10-acre, and 1/20-acre sample plots and the cluster of 1/24-acre plots were more representative of the small hardwood component of these stands than the single point or point cluster (tables 6-7).

Table 1.—*Average number of loblolly pine trees per acre 5.0 inches dbh and greater for the 76-acre population and the estimates of this characteristic for 49 sample plots using various sampling unit configurations*

Population Value – 61.5 trees/acre

Sampling unit	Mean	Standard error	95% Confidence interval Lower limit	95% Confidence interval Upper limit	Population value in the Interval?
	Trees/acre				
4 Plot Cluster	64.5	4.8	54.8	74.2	YES
1/6 Acre Plot	65.5	3.4	58.6	72.4	YES
5 Point Cluster	68.8	6.1	56.6	81.1	YES
7.5 BAF Point	63.8	4.1	55.6	72.1	YES
1/10 Acre Plot	65.5	4.2	57.0	74.0	YES
1/20 Acre Plot	71.4	4.9	61.5	81.4	YES

Table 2.—*Average basal area per acre for loblolly pine trees 5.0 inches dbh and greater for the 76-acre population and the estimates of this characteristic for 49 sample plots using various sampling unit configurations*

Population value – 64.3 square feet/acre

Sampling unit	Mean	Standard error	95% Confidence interval Lower limit	95% Confidence interval Upper limit	Population value in the interval?
	- - - - - - - - sq ft/acre - - - - - - -				
4 Plot Cluster	67.1	3.5	60.2	74.1	YES
1/6 Acre Plot	68.2	2.9	62.4	74.1	YES
5 Point Cluster	68.7	3.7	62.0	75.7	YES
7.5 BAF Point	66.3	3.0	60.3	72.2	YES
1/10 Acre Plot	66.1	3.7	58.7	73.5	YES
1/20 Acre Plot	73.4	4.2	65.0	81.8	NO

Table 3.—*Average cubic foot volume per acre for loblolly pine trees 5.0 inches dbh and greater for the 76-acre population and the estimates of this characteristic for 49 sample plots using various sampling unit configurations*

Population value – 2250 cubic feet/acre

Sampling unit	Mean	Standard error	95% Confidence interval Lower limit	95% Confidence interval Upper limit	Population value in the interval?
	- - - - - - - - cu ft/acre - - - - - - -				
4 Plot Cluster	2,318	128	2,059	2,576	YES
1/6 Acre Plot	2,388	115	2,155	2,621	YES
5 Point Cluster	2,380	125	2,127	2,632	YES
7.5 BAF Point	2,315	114	2,084	2,546	YES
1/10 Acre Plot	2,316	140	2,034	2,599	YES
1/20 Acre Plot	2,562	159	2,240	2,883	YES

Table 4.—*Average proportion of fusiform rust for loblolly pine trees 5.0 inches dbh and greater for the 76-acre population and the estimates of this characteristic for 49 sample plots using various sampling unit configurations*

Population value – 0.23

Sampling unit	Mean	Standard error	95% Confidence Interval Lower limit	95% Confidence Interval Upper limit	Population value in the interval?
	- - - - - - - Proportion infected - - - - - -				
4 Plot Cluster	0.26	0.02	0.21	0.31	YES
1/6 Acre Plot	0.24	0.03	0.20	0.29	YES
5 Point Cluster	0.27	0.03	0.20	0.33	YES
7.5 BAF Point	0.25	0.02	0.20	0.30	YES
1/10 Acre Plot	0.25	0.03	0.19	0.30	YES
1/20 Acre Plot	0.27	0.04	0.19	0.35	YES

Table 5.—*Average Scribner board foot volume for the 76-acre natural loblolly pine population and the estimates of this characteristic for 49 sample plots using various sampling unit configurations*

Population value – 3,982 board feet/acre

Sampling unit	Mean	Standard error	95% Confidence interval Lower limit	Upper limit	Population value in the interval?
	- - - -	- - - bd ft/acre	- - -	- - -	
4 Plot Cluster	4,466	393	3,672	5,260	YES
1/6 Acre Plot	4,155	296	3,557	4,753	YES
5 Point Cluster	4,229	299	3,624	4,833	YES
7.5 BAF Point	4,163	301	3,556	4,771	YES
1/10 Acre Plot	4,035	361	3,306	4,764	YES
1/20 Acre Plot	4,289	429	3,423	5,155	YES

Table 6.—*Average number of hardwood trees per acre 1.0 to 4.9 inches dbh for the 76-acre population and the estimates of this characteristic for 49 samples using various sampling unit configurations*

Population value – 55.1 trees/acre

Sampling unit	Mean	Standard error	95% Confidence interval Lower limit	Upper limit	Population value in the interval?
	- - - -	- - - trees/acre	- - -	- - -	
4 Plot Cluster	50.5	11.2	27.9	73.1	YES
1/6 Acre Plot	48.2	6.8	34.4	62.1	YES
5 Point Cluster	2.4	1.7	0	5.9	NO
7.5 BAF Point	6.3	5.1	0	16.6	NO
1/10 Acre Plot	47.8	8.1	31.3	64.2	YES
1/20 Acre Plot	51.8	9.4	32.8	70.9	YES

Table 7.—*Average basal area per acre (sq ft) for hardwood trees 1.0 to 4.9 inches dbh for the 76-acre population and the estimates of this characteristic for 49 sample plots using various sampling unit configurations*

Population value – 1.7 square feet/acre

Sampling unit	Mean	Standard error	95% Confidence interval Lower limit	Upper limit	Population value in the interval?
	- - - -	- - - sq ft/acre	- - -	- - -	
4 Plot Cluster	1.4	0.6	0.2	2.6	YES
1/6 Acre Plot	1.6	0.2	1.1	2.0	YES
5 Point Cluster	0.3	0.2	0.0	0.6	NO
7.5 BAF Point	0.5	0.3	0.0	1.1	NO
1/10 Acre Plot	1.4	0.2	0.9	1.9	YES
1/20 Acre Plot	1.5	0.3	0.9	2.0	YES

Site index estimates (base age 50) were calculated for the pine component of these stands. The "population" value was determined by using all dominant and codominant trees that were measured for total height and cored for age at 1 foot from the ground. The sample unit values were calculated for each sample unit using all dominant and codominant trees measured for total height and cored for age at either 1 foot or 4.5 feet off the ground. Note that the average difference of 3 years between age at 4.5 feet and age at 1 foot was added to ring counts from 4.5 feet. Thus, each sampling unit had a site index value calculated from a different number of measured trees. The estimates indicate that all sampling units produced reasonable site index estimates using this method (table 8).

Standard field procedures used on FIA ground locations require field crews to select a single tree to use in obtaining an estimate of site index for the sampling location. This tree is measured for total height and cored for age and used to determine site index. This estimate of site index is very weak at best because it is based on a single tree. In fact, Johnson and Carmean (1953) showed that the use of three sample trees to estimate site index for Douglas-fir stands resulted in a bound on the estimated site index of more than 25 feet. Comparison of estimated site index values from the single "site" tree selected by the field crew with the average of the large sample of dominant and codominant trees measured for total height and cored for age at 1 foot from the ground on each large sample plot shows that differences at a given location are as large as 26.8 feet (table 9). The average site index for the hypothetical population was 80.6 feet, while the average site index calculated from the single site tree at each location was 86.7 feet. The 95 percent confidence interval for this estimate has a lower value of 84.1 feet and an upper value of 89.3 feet. Clearly, there is a great deal of error associated with estimating site index with a single site tree.

DISCUSSION

All sampling units produced reasonable estimates of pine overstory population parameters investigated for natural loblolly pine stands in the Georgia piedmont. The clusters of plots and points resulted in more highly variable estimates than a single point or single fixed-area sample plots. The 1/10-and 1/20-acre fixed-area sample plots produced more variable estimates than the 1/6-acre fixed-area sample plot. However, confidence intervals for these smaller fixed-area sample plots enclosed the population parameter for all stand characteristics except for the estimate of basal area per acre for the 1/20-acre sample plot.

Estimates of the small hardwood understory component of these stands were highly variable for all sampling units. The fixed-area plot cluster as well as all single fixed-area plots produced confidence intervals that enclosed the population parameter for both trees per acre and basal area per acre. However, the cluster of points and single point produced very poor biased estimates for both of these characteristics. The difference in the accuracy of the estimates of the understory hardwood component for the plot cluster and point cluster seems illogical. Both methods made use of 1/300-acre fixed-area sample plots. In fact, the cluster of points uses five of these plots while the cluster of plots uses four. Thus, even with more intensive sampling, the point cluster resulted in poor estimates of number of small hardwoods in the understory. As stated above, the understory hardwood component was patchy and very variable. A total of 33 hardwood trees from 1.0 to 4.9 inches dbh were tallied on the 49 clusters of 1/300-acre plots associated with the four-plot clusters, while only 2 hardwood trees from 1.0 to 4.9 inches dbh were tallied on the 49 clusters of 1/300-acre plots associated with the five-point clusters. Clearly,

Table 8.—*Average site index (base age 50) for the 76-acre natural loblolly pine population and the estimates of this characteristic for 49 sample plots using various sampling unit configurations*

Population value – 80.6 feet

Sampling unit	Mean	Standard error	95% Confidence interval Lower limit	95% Confidence interval Upper limit	Population value in the interval?
	- - -	- - -	- feet -	- - -	
4 Plot Cluster	81.4	1.1	79.2	83.6	YES
1/6 Acre Plot	82.2	1.2	79.9	84.6	YES
5 Point Cluster	82.6	1.0	80.6	84.7	YES
7.5 BAF Point	84.9	1.6	81.6	88.2	NO
1/10 Acre Plot	81.7	1.3	79.0	84.4	YES
1/20 Acre Plot	80.7	1.4	77.7	83.6	YES

Table 9.—*Site index estimates (feet) for each large sample plot calculated with a single site tree selected by the field crew (SI-Crew) as well as calculated with a the large sample of dominant and codominant trees measured for total height and age (SI-Large)*

Plot	SI-Crew	SI-Large	Difference
1	102.1	82.4	19.7
2	104.8	83.0	21.8
3	87.5	88.2	-0.7
4	81.3	76.5	4.8
5	82.5	92.0	-9.5
6	101.2	90.0	11.2
7	89.3	88.2	1.1
8	102.6	98.3	4.3
9	88.7	85.9	2.8
10	88.9	87.5	1.4
11	106.4	79.6	26.8
12	94.9	88.0	6.9
13	76.8	75.2	1.6
14	72.4	73.3	-0.9
15	81.8	75.3	6.5
16	88.1	84.8	3.3
17	94.3	80.8	13.5
18	85.5	74.6	10.9
19	87.5	85.3	2.2
20	76.4	79.5	-3.1
21	74.5	76.9	-2.4
22	82.9	84.0	-1.1
23	93.9	75.6	18.3
24	93.0	78.9	14.1
25	82.2	82.5	-0.3
26	74.8	68.5	6.3
27	76.3	82.1	-5.8
28	80.8	72.3	8.5
29	84.3	79.9	4.4
30	80.3	70.4	9.9
31	72.9	74.3	-1.4
32	86.1	59.9	26.2
33	76.3	61.3	15.0
34	91.0	78.5	12.5
35	78.8	73.8	5.0
36	98.5	84.4	14.1
37	76.6	81.3	-4.7
38	84.9	80.0	4.9
39	82.9	81.9	1.0
40	75.4	82.5	-7.1
41	83.7	81.4	2.3
42	83.6	91.3	-7.7
43	92.4	93.3	-0.9
44	88.7	86.4	2.3
45	94.3	87.9	6.4
46	107.6	91.2	16.4
47	88.8	72.9	15.9
48	81.9	68.5	13.4
49	88.2	81.0	7.2

placement of the point clusters resulted in a very non-representative sample of the population. This is the danger associated with using such a small sampling unit to sample highly variable populations.

Site index estimates based on a single "site" tree selected by the field crew consistently overpredicted estimates based on a large number of sample trees. These overestimates resulted in a positive bias of approximately 6 feet across our hypothetical population. However, when several dominant and codominant trees from each sampling unit were used to estimate site index, resulting estimates were very close to the population value. It seems logical that an overestimate of site index will result from the choice of a single site tree since field crews will usually be inclined to choose the tallest tree in the neighborhood of the sample plot.

Based on our field study, all sampling units evaluated were adequate for estimating the pine overstory component of mature natural loblolly pine stands. However, there is higher variability associated with smaller fixed-area plots and with clusters of small fixed-area plots or large BAF points. Use of four or five 1/300-acre sample plots to estimate highly variable hardwood understories in this stand type showed that resulting estimates were highly variable and potentially seriously biased. Site index estimates based on a single subjectively chosen site tree result in serious overestimates of site index. This will most likely present a problem when some type of plot update procedures are implemented for the AFIS and SAFIS inventory designs.

RECOMMENDATIONS

Based on this field study, we believe that the current sample unit design consisting of four 1/24-acre plots will produce reasonable unbiased estimates of important stand characteristics. However, the use of the very small 1/300-acre sample plots for estimating highly variable stand understories is questionable. We recommend that consideration be given to measurement of all trees falling on the 1/24-acre sample plots without regard to diameter. This should result in better understory estimates that will likely be necessary for model update procedures for AFIS and/or SAFIS. Finally, we believe it is prudent to measure additional dominant and codominant trees for total height and age so that realistic site index estimates can be obtained. If two dominant or codominant trees were obtained on each of the four subplots, the site index estimate would be realistic and useful in plot update procedures.

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