Anomalous diameter distribution shifts estimated from FIA inventories through time

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Summary

In the past decade, the United States Department of Agriculture Forest Service's Forest Inventory and Analysis Program (FIA) has replaced regionally autonomous, periodic, state-wide forest inventories using various probability proportional to tree size sampling designs with a nationally consistent annual forest inventory design utilizing systematically spaced clusters of fixed-area plots. This has resulted in significant changes in the spatial-temporal distribution of observations on the nation's forest resource. This paper discusses the resulting changes in the observation of the distribution of tree diameters measured at 1.37 m above ground level. We show that in three of the four FIA regions, a significant portion of the upper end of the diameter distribution has thus far gone unobserved by the new inventory design. We conclude that the reason is not that the larger diameter trees have become less common but rather that there is a low enough probability of observing these trees that they are not being observed. This postulate is supported by the observation that large-diameter trees are not missing from the data acquired by the fourth FIA region (the Pacific Northwest), which uses an additional sampling mechanism for large-diameter trees. We explore the implications of this effect in addition to potential solutions.

Since the 1930s, the individual, regional Forest Inventory and Analysis Units concentrated on increasing their efficiency of operation, often by improving the efficiency of the sample design for the specific forest conditions and the attributes that were considered the most important within their region while meeting national objectives. Despite a rich diversity of objectives between regions, all of the regions converted to probability proportional to size (pps) sampling for the selection of sample trees, using clusters of horizontal point samples, beginning in the late 1950s. This was done because, in these designs, trees are selected in proportion to their basal areas and basal area is highly correlated with important variables such as wood volume, age and stand size. More recently, growing environmental awareness has led to increased interest in forest biomass and carbon, which are highly correlated with volume and basal area.

The diversity of methods between regions presented challenges for those wishing to compare results across regions. This, in combination with other considerations, such as an expanding scope and set of objectives for the program, helped to give rise to a clarion call to standardize methods across regions (McRoberts, 2005). The resulting national design uses nested, fixed-area plot clusters to select trees, within size categories, with equal probability (or probability proportional to size category, ppsc), rather than the previously favoured continuous-pps (horizontal point) sample clusters. The general field plot cluster for the new design is depicted in Figure 1. As seen in the figure, and discussed in Roesch (2007a), the cluster design allows for an optional macroplot surrounding each sub-plot for an increased sample of larger diameter trees. Only one of the four Forest Inventory and Analysis Program (FIA) regions (the Pacific Northwest Research Station) uses the macroplot option extensively, while two of the FIA regions (the Southern Research Station and the Northern Research Station) do not use it at all. Given the potentially significant increase in sampling effort required by the use of the macroplot clusters, we might wonder what differences in efficiency for meeting program goals are being experienced through their use.

Figure 2 shows the number of sample trees per plot in 5-cm-diameter classes averaged over (1) all previous periodic inventories (mostly using pps designs) and (2) over the annual inventory since its inception, for each of the four FIA regions, included in FIA's publicly available database, FIADB 4.0 (Anonymous, 2009). This figure shows that these two general sampling approaches have led to quite different allocations of effort in observing the diameter distributions (notably for the smallest and largest diameters) in each of the four regions. Note that observation of the upper end of the diameter distribution was

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more complete in the prior periodic inventories in three of the four regions. Owing to the fact that design-based estimators provide estimates only for levels of an attribute that are actually observed, design-based estimates for the diameter distribution resulting from these two different inventory approaches would be quite different in these three regions. Because one sampling approach succeeded the other in time, and both are theoretically unbiased, one might conclude that there has been a general change in the diameter distribution of the tree population in each region over time. Rather, it is more likely that the difference in the use of the macroplots, in conjunction with the eschewing of a continuous-pps design, has led to divergence between regions in the ability to characterize the diameter distribution, which is one of the most basic forest mensurational attributes. Naturally, shifting sampling effort to increase the probability of observing the larger diameter trees would alleviate the problem. Although there are many ways to accomplish this, here we will focus on those approaches that do not require the establishment of additional sample locations or additional sample stages.

We note that there are other very valid reasons to increase the sample of large trees besides achieving a more thorough observation of the diameter distribution and the obvious relationship to tree volume. These other reasons are immediately applicable to the ever-expanding goals of the FIA. For one thing, big trees are rare, and, therefore, knowledge of their characteristics and contributions to the general ecology of the forest is extremely important, but elusive. Consequently, a greater number of the trees in old-growth forests, which usually contain very large trees,

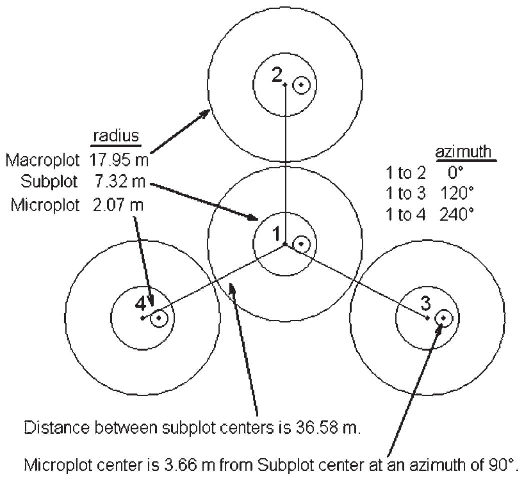

Figure 1. The FIA plot cluster samples trees with probability proportional to size class (ppsc). The ppsc design contains a cluster of four microplots (for seedlings and saplings), a cluster of four sub-plots (for trees greater than 12.7 cm d.b.h.) and an optional cluster of four macroplots (for large-diameter trees).

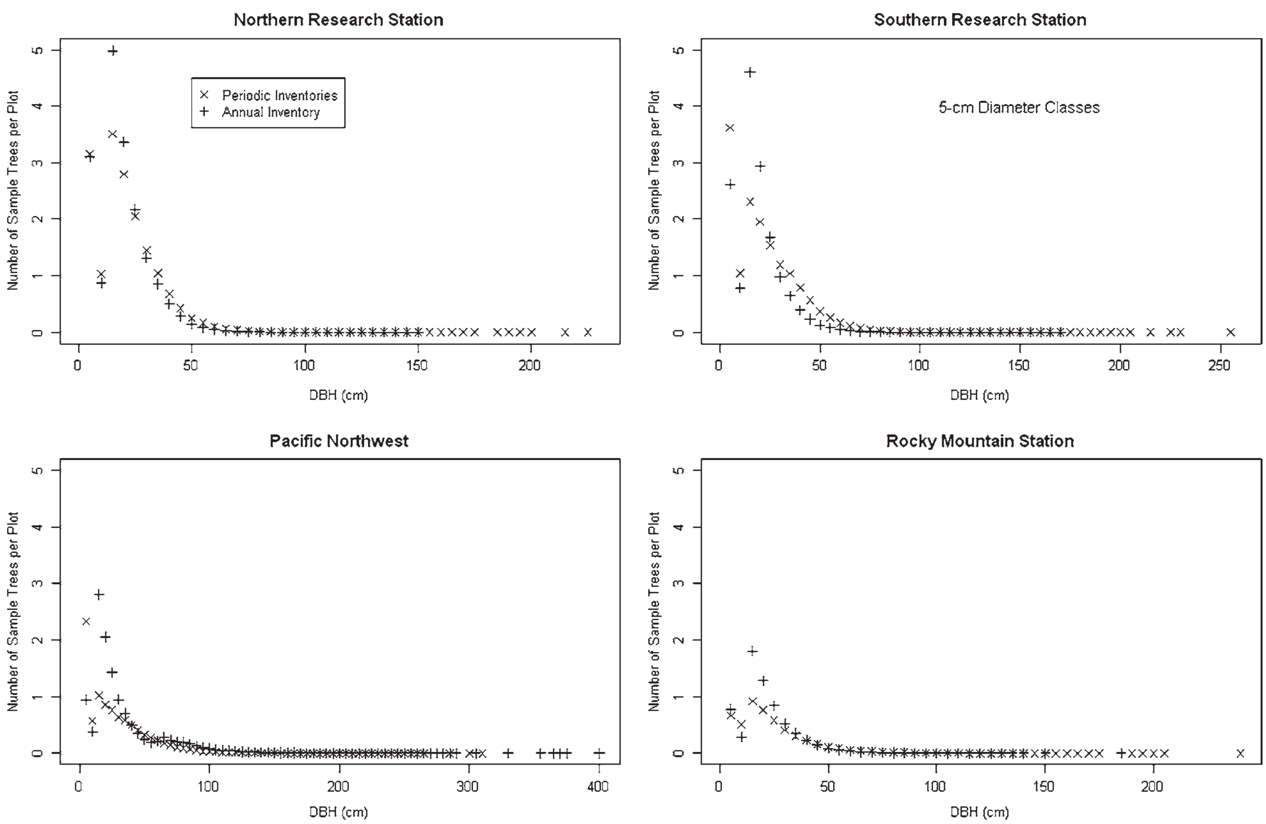

Figure 2. The proportion of trees sampled in each of the 5-cm-diameter classes (i.e. the population diameter distribution in 5-cm classes) averaged over (a) all periodic inventories included in FIADB 4.0 and (b) the annual inventory since its inception, for each of the four FIA regions.

would be sampled with a pps design or by utilizing a special category for large trees in a ppsc design. Large trees are also an important component to consider when evaluating the availability of habitat for many species of wildlife. On the other hand, in certain stand structures, there may be very few very small trees, and a pps design that is appropriate for the major stand component might result in an inadequate sample of these very small trees. For this reason, many forest inventories use fixed-area plots for very small trees (say less than or equal to 12 cm in diameter at breast height (d.b.h.)), regardless of the design used to sample trees larger than that.

Because of well-known stand dynamics, the sampling of trees by a ppsc design rather than a pps intensifies the sample of small trees within each category relative to the sample of large trees within that category at an exponential rate. If this distribution of sampling effort leads to an exponential increase in the knowledge of the state of forest attributes, then that particular distribution of sampling effort would be justified. That is, if measuring many of the smaller trees within a size category for each of the larger trees within that category gave one knowledge worth more than measuring a more balanced number of each size, then sampling trees with a ppsc design would be beneficial. This disparity within categories decreases as the number of categories increases. As the number of categories in a ppsc design increases, the closer it becomes to a pps design.

To date, there has not been an attempt to demonstrate, in the literature, an advantage to measuring many more small trees than large trees, relative to the goals of any national forest inventory program. If, in fact, fewer small trees could be measured with no significant loss of information, then that sampling effort could be shifted towards the measurement of more large trees, which currently appear to be under-represented in the sample.

Below, we clarify the sampling effort relative to the diameter distribution for these various designs. Because the sampling of natural resources is ultimately limited by available funding, we explore possibilities to better sample the range of diameters in the population while tempering our conclusions with a perceived expected cost of each approach. We also keep in mind that no sample design is a panacea, and it is this same limited funding that invariably leads to quite complex designs for large-area forest inventories, as the inventory designers attempt to maximize the efficiency of the sample in order to achieve a wide range of estimation goals. For examples, we refer the interested reader to Tomppo *et al.* (1991), Kleinn (2002), Schadauer *et al.* (2007), Vidal *et al.* (2007), Moore *et al.* (2007), Kändler (2009), Hirata *et al.* (2009), Tomppo and Siitonen (1991) and Härkönen *et al.* (2010).

Methods

An obvious approach to sample fewer small trees would be, of course, to use horizontal point samples to select sample trees. To show the potential savings of using a horizontal point sample for the smaller trees, we filtered the data from the national design annual inventory plots by re-sampling from sub-plot centre, using basal area factors of 2, 6, 7 and 9 m^2 ha^{-1}. We then calculated 95 per cent confidence intervals (CIs) for each sample to see how many fewer small trees could have been measured with substantially the same expected result. We do this at two scales. At both scales, because we are combining many different but similar sample designs in order to make estimates, we assume that successive inventories (or cycles in FIA terminology) within each state are independent. This assumption allows us to weight individual plots appropriately by the design effect for each inventory as described within FIADB and then combine estimates across inventories without considering covariances between estimates made at some of the same plot locations but potentially under different designs. At a gross scale, we first obtain estimates of the diameter distribution over all trees for each state and then weight the results in each diameter class by the most recent estimate of forest area in each state to obtain an estimated diameter distribution for each FIA region under each sampling scheme.

Subsequently, at a fine scale, we estimate the diameter distribution (in 5-cm classes) for each of the 48 FIA species groups (Anonymous, 2009) observed in each of 176 FIA inventory units in 46 states (four states (Hawaii, Wyoming, Oklahoma and New Mexico), as well as individual inventory units in Texas and Alaska, did not yet have adequate data for these analyses at the time of this study) of the US for each of the above-described samples.

We summarize the results at the gross scale by the average number of trees per plot observed within each of the 5-cm-diameter classes (i.e. the sample diameter distribution in 5-cm classes). The results are given for (1) all periodic inventories included in FIADB 4.0 and (2) the annual inventory since its inception, for each of the four FIA regions, along with the resulting average number of sample trees remaining after re-sampling (or filtering) the annual inventory with each of the point samples.

At the fine scale, we estimate the diameter distribution (in 5-cm classes) in each inventory unit of the FIA species groups found in each unit for each of the samples. We calculate the proportion of overlapping 95 per cent CIs between the periodic and annual sampling schemes and between the annual and re-sampled annual schemes for each diameter class.

Results

In Figure 3, we give the average number of trees per plot within each of the 5-cm-diameter classes (i.e. the sample diameter distribution in 5-cm classes) grouped by (1) all periodic inventories included in FIADB 4.0, (2) the annual inventory since its inception for each of the four FIA regions and, (3) the annual inventory data re-sampled with a point samples of basal area factor (BAF) of 2, 6, 7 and 9 m^2 ha^{-1}. Figure 3 shows what sampling effort would have been avoided at the lower end of the diameter distribution if one of the point samples of these successively increasing BAFs had

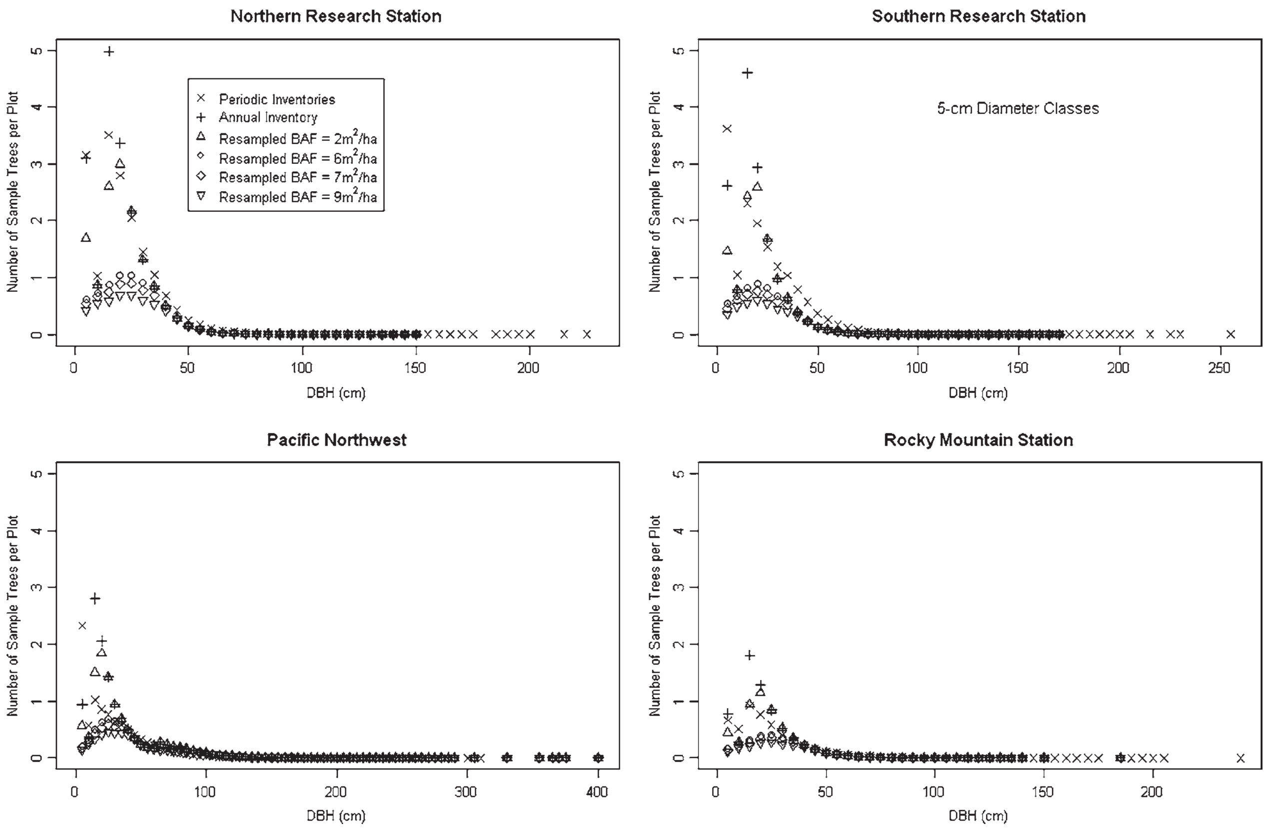

Figure 3. The average number of trees per plot observed in each sample within each of the 5-cm-diameter classes (i.e. the sample diameter distribution in 5-cm classes) for (a) all periodic inventories included in FIADB 4.0, (b) the annual inventory since its inception for each of the four FIA regions, (c) the annual inventory data re-sampled with point samples of BAFs of 2, 6, 7 and 9 m^2 ha^{-1}.

been used rather than the fixed-area plot cluster. Arguably, this is the sample effort that could have been shifted to the larger diameters if there is no indication of a substantial loss of information at a particular BAF.

Corresponding to Figure 3, in Table 1, we give the proportions and half-widths for the 95 per cent CIs for the estimates in each of the 5-cm-diameter classes (from 5 to 45 cm) grouped by (1) all periodic inventories included in FIADB 4.0 and (2) the annual inventory since its inception for each of the four FIA regions. Additionally, we show the proportions and half-widths for the 95 per cent CIs for the estimates obtained after re-sampling the annual inventory data with point samples of BAF 2, 6, 7 and 9 m^2 ha^{-1}. Table 1 shows that even with the greatly reduced sample resulting from the point-sampling filters reflected in Figure 3, not much confidence is lost for the estimates at the lower end of the diameter distribution. This indicates that, at least at this gross scale, far more small trees are being measured with the current design than are actually needed for making diameter distribution estimates with a high degree of confidence.

A simple way of assessing the relative loss of information at the fine scale for a complex survey would be to examine agreement between the CIs obtained for each sampling scenario for variables of high interest. Tables 2 and 3 give the results from estimating the diameter distribution (in 5-cm classes) in each inventory unit of the FIA species groups found in each unit for each of the samples. The proportion of overlapping 95 per cent CIs between sampling schemes for each diameter (at breast height, i.e. d.b.h.) class from 5 to 45 cm is shown. Table 2 shows the proportion of intervals estimated from all annual inventory data that overlap with the same intervals estimated from all of the periodic inventory data. Table 3 shows the proportion of overlapping intervals between the estimates resulting from re-sampling the annual inventory data with basal area factors of 2, 6, 7 and 9 m^2 ha^{-1}, respectively, with the estimates from the annual inventory data. We note from Table 2 that the 95 per cent CIs for the older periodic intervals often do not overlap with any of the CIs based on the more recent annual inventories. This supports our earlier observation that the estimated diameter distributions are different for the earlier inventories than for the more recent inventories. This shows that, at the scale of species group within inventory units, there is a substantial difference in the diameter distributions estimated from the current fixed-area annual design relative to the previous periodic probability proportional to size designs. At the

Table 1: The estimated regional proportions and the half-widths of the 95% CIs for each of the 5-cm-diameter classes (from 5 to 45 cm) pooled over (a) all periodic inventories and (b) the annual inventory

d.b.h. class (cm)	Proportions						95% CIs					
	Periodic	Annual	Resamples				Periodic	Annual	Resamples			
			BAF	BAF	BAF	BAF			BAF	BAF	BAF	BAF
			2 m^2 ha^{-1}	6 m^2 ha^{-1}	7 m^2 ha^{-1}	9 m^2 ha^{-1}			2 m^2 ha^{-1}	6 m^2 ha^{-1}	7 m^2 ha^{-1}	9 m^2 ha^{-1}
NRS												
5	0.5618	0.6099	0.6137	0.6189	0.6174	0.6157	0.0227	0.0261	0.0294	0.0375	0.0391	0.0423
10	0.1905	0.1716	0.1696	0.1674	0.1681	0.1689	0.0075	0.0075	0.0074	0.0077	0.008	0.0086
15	0.0956	0.0787	0.0787	0.0778	0.0782	0.0788	0.0029	0.0025	0.0027	0.0033	0.0035	0.0038
20	0.0632	0.0532	0.0525	0.0519	0.0522	0.0525	0.0018	0.0017	0.0017	0.0021	0.0022	0.0023
25	0.0382	0.0344		0.0334	0.0334	0.0335	0.0011	0.0012		0.0013	0.0014	0.0015
30	0.0216	0.0208		0.0201	0.0201	0.0202	0.0007	0.0008		0.0008	0.0009	0.001
35	0.0132	0.0135		0.0131	0.0131	0.013	0.0005	0.0006		0.0006	0.0006	0.0007
40	0.0073	0.0079			0.0077	0.0077	0.0003	0.0004			0.0004	0.0005
45	0.0039	0.0044				0.0043	0.0002	0.0003				0.0003
SRS												
5	0.6862	0.6019	0.6063	0.6062	0.6032	0.6033	0.0224	0.0218	0.0244	0.0313	0.0325	0.0353
10	0.1465	0.1805	0.1777	0.1778	0.1792	0.1803	0.0052	0.0069	0.0068	0.0071	0.0074	0.0079
15	0.0673	0.0849	0.0856	0.0862	0.0869	0.0865	0.0021	0.0027	0.0029	0.0033	0.0035	0.0036
20	0.0411	0.0541	0.0531	0.053	0.0534	0.0532	0.0013	0.0018	0.0018	0.002	0.0021	0.0022
25	0.0236	0.0311		0.0305	0.0307	0.0306	0.0007	0.001		0.0011	0.0012	0.0012
30	0.0137	0.0181		0.0176	0.0177	0.0175	0.0004	0.0006		0.0007	0.0007	0.0007
35	0.0091	0.012		0.0116	0.0117	0.0116	0.0003	0.0005		0.0005	0.0005	0.0005
40	0.0055	0.0073			0.0071	0.0071	0.0002	0.0003			0.0003	0.0004
45	0.0031	0.0043				0.0042	0.0001	0.0002				0.0002
PNW												
5	0.5447	0.4486	0.4546	0.4526	0.4551	0.4549	0.0321	0.0351	0.0392	0.0495	0.0511	0.0541
10	0.1485	0.1794	0.1735	0.1756	0.1754	0.1783	0.0105	0.0129	0.0125	0.0131	0.0135	0.0143
15	0.09	0.1073	0.1067	0.1074	0.1063	0.1062	0.0053	0.0053	0.0056	0.0066	0.0068	0.0072
20	0.0663	0.0786	0.0761	0.0755	0.0751	0.0741	0.0037	0.0037	0.0036	0.0042	0.0043	0.0045
25	0.0462	0.0546		0.0527	0.0526	0.0521	0.0025	0.0026		0.0027	0.0028	0.0029
30	0.0303	0.036		0.0348	0.0346	0.0346	0.0017	0.0018		0.0018	0.0019	0.002
35	0.0223	0.0267		0.0258	0.0258	0.0257	0.0012	0.0014		0.0014	0.0014	0.0015
40	0.0155	0.0188			0.0181	0.018	0.001	0.001			0.001	0.001
45	0.0106	0.0133				0.0128	0.0007	0.0008				0.0008
RMS												
5	0.4604	0.5205	0.5233	0.5329	0.5323	0.5368	0.0379	0.0469	0.0508	0.0624	0.0648	0.0692
10	0.1953	0.1889	0.1875	0.1833	0.1837	0.1823	0.0134	0.0163	0.0162	0.0164	0.0169	0.0176
15	0.119	0.0966	0.0966	0.0949	0.0948	0.0943	0.0067	0.0065	0.0068	0.0077	0.0079	0.0083
20	0.0826	0.0686	0.0682	0.0671	0.0673	0.0664	0.0043	0.0045	0.0045	0.005	0.0051	0.0053
25	0.0526	0.0451		0.0442	0.0443	0.0438	0.0026	0.0029		0.0031	0.0031	0.0033
30	0.0319	0.0281		0.0269	0.027	0.0266	0.0016	0.0019		0.0019	0.0019	0.002
35	0.0211	0.019		0.0184	0.0184	0.0181	0.0011	0.0013		0.0013	0.0014	0.0014
40	0.0133	0.0122			0.0118	0.0117	0.0008	0.0009			0.0009	0.0009
45	0.0084	0.0077				0.0074	0.0006	0.0007				0.0007

Also given are proportions and the half-widths for their 95% CIs obtained by filtering the annual inventory data with point samples of BAFs 2, 6, 7 and 9 m^2 ha^{-1}.

same time, Table 3 shows exceptional agreement between the estimated diameter distributions from the re-sampled annual data with those estimated under the fixed-area design. This indicates that a substantial reduction could be made in the number of trees sampled at the lower end of the diameter distribution with essentially the same results, even at this fine scale.

Table 2: Proportion of the 95% CIs for estimates of the proportion of trees in each 5-cm-diameter class (at breast height, i.e. d.b.h.) that overlap between all periodic and all annual inventories from each of the 48 FIA species groups in each of 176 inventory units

d.b.h. class (cm)	Proportion
5	0.9247
10	0.9118
15	0.8030
20	0.7674
25	0.7549
30	0.7493
35	0.7782
40	0.7863
45	0.8082
50	0.8131
55	0.8469
60	0.8623
65	0.8633
70	0.8640
75	0.8839
80	0.9013
85	0.8888
90	0.9118
95	0.9299
100	0.9428
105	0.9491
110	0.9627
115	0.9714
120	0.9700
125	0.9738
130	0.9843
135	0.9829

The data are from 46 of the 50 states in the US.

Conclusions

A quite striking result of this analysis is how the current sample design has eliminated the observation of large trees in three of four regions in the US. It would be easy for a casual observer to conclude that absence of large trees from the sample is the result of a shifting diameter distribution in the population. In the case at hand, it is much more likely that the larger trees are simply rare enough to be missed by the sample.

What we are observing is actually the result of sampling variance that might mistakenly be interpreted to be bias. In general, the application of a design-unbiased estimator will lead to estimates that appear to be biased when all of the elements in a category go unobserved if the category had a positive probability of being observed. That is, the large sample properties that tell us we are drawing an unbiased sample still hold; however, the rarity of the larger trees increases the probability that we will not observe any of them in a particular sample. If we drew the same size sample of plot locations thousands of times and took a mean, it would closely approximate the population mean. Unfortunately, we really only draw our sample once, resulting in a single set of plot locations that are separated by enough distance relative to the distribution of large trees to have missed almost all of the population of large trees. Note that there was also some probability of observing so many large trees that we would have made an extreme overestimate of the proportion of these larger diameters in the diameter distribution.

This leads us to the conclusion that, with respect to the estimation of tree diameter distribution, the current implementation of the FIA national design is performing sub-optimally in some of the regions because there is too small a probability of reliably observing large-diameter trees, resulting in a sample that has so far failed to observe a somewhat rare but significant segment of the diameter distribution. We are left with the delicate task of recommending solutions without jeopardizing any of the many desirable features of an otherwise successful national forest inventory program (as described by ourselves and others, i.e. Bechtold and Scott, 2005; Czaplewski and Thompson, 2009; Reams *et al.*,

Table 3: Proportion of overlapping 95% CIs between estimates from the annual inventory and each of the filtered resamples for estimated proportion of trees (at breast height, i.e. d.b.h.) in 5-cm-diameter classes from each of the 48 FIA species groups in each of 176 inventory units

d.b.h. class (cm)	BAF 2 $m^2\ ha^{-1}$ resample to annual	BAF 6 $m^2\ ha^{-1}$ resample to annual	BAF 7 $m^2\ ha^{-1}$ resample to annual	BAF 9 $m^2\ ha^{-1}$ resample to annual
5	0.9990	0.9892	0.9829	0.9773
10	1.0000	0.9997	0.9979	0.9962
15	0.9948	0.9759	0.9714	0.9582
20	0.9997	0.9857	0.9773	0.9693
25		0.9913	0.9857	0.9808
30		0.9944	0.9909	0.9881
35		0.9969	0.9937	0.9923
40			0.9979	0.9965
45				0.9986

The data are from 46 of the 50 states in the US.

2004, 2005; Roesch, 2007b; Van Deusen, 2000). There are a few easily implemented solutions:

1 FIA could begin using macroplots everywhere. The problem currently observed in the data for three of the four FIA units regarding the missing segments of the diameter distributions from the sample would be solved (as indicated by the distributions observed by the periodic inventories). This option has the additional advantage of maintaining continuity with the current annual system and would lead to better compatibility between regions. Neither would it result in any loss of utility of previously collected data nor would it require any change in the current documentation. For three of the regions, it would result in increased field time, the extent of which can be controlled by the threshold diameter used to define the macroplot sample.
2 FIA could transition to a pps design. Compatibility with previously collected annual inventory data could be facilitated by using the same sampling loci as in the current design (Figure 1) in one of three ways:

(a) Use the microplot and sub-plot centres to select trees with a pps sample (within the same size categories as currently sampled with the microplot and sub-plot, respectively) or,
(b) Keep the fixed-area microplots and use the sub-plot centres to select trees greater than or equal to 12.7 cm in d.b.h. with a pps sample.
(c) Keep the fixed-area microplot and optional macroplot samples and sample the population of trees currently being sampled by the sub-plots in each region with a pps sample from the sub-plot centres.

Option 2(a) would give a size-balanced sample, while 2(b) would be size balanced for trees >12.7 cm d.b.h. Option 2(c) would have most or all of the benefits of Options 2(a) and (b), depending on one's viewpoint and would set a search distance limit for the largest trees in the case of regions using the macroplots. The results reported here indicate that, like Option 1, Options 2 (a), (b) and (c) would improve the observation of the diameter distribution in three of the regions. Unlike Option 1, these options would also reduce the cost of tree measurement in all of the regions, since fewer trees would be sampled.

We characterized the above potential solutions as easily implemented because current FIA data-processing procedures and the database already contain all of the features necessary to incorporate them. This is true especially in light of the fact that the same loci would be used to select trees within size categories. The most obvious of these already existing features are the ability to utilize individual tree probabilities of inclusion and an indicator function to identify which trees to use in growth calculations. At the same time, we must acknowledge a distinction between the ease of implementation and the desirability of implementation for a particular sample design change. A highly desirable element in long-term monitoring efforts is consistency in the sample design, which leads to a greater interpretability of the results. From this perspective, Option 1 has a clear advantage over Options 2(a), (b), and (c). Although the statistical consequences of incorporating any of these options are well known, and arguably similar save for differences in efficiency, the perception of adopting Option 1 would be one of adopting an already defined and partially in-use design feature, while adopting any variant of Option 2 would be perceived by many to be an almost radical design change. Additionally, Option 1 would not require any change in the existing documentation.

With respect to growth estimation, any change in tree selection probabilities will have both desirable and undesirable consequences from particular points of view. For example, the variants of Option 2 would result in the remeasurement of fewer trees than had been measured previously. This is an intended consequence that could be viewed as a reduction in the utility of the data from those prior measurements. Note, however, that this reduction in utility increases as diameter decreases, and our prior arguments suggest that many of these smaller diameter measurements have low utility to begin with. In the pps option, the loci for the microplot and sub-plot are kept for sampling within size categories to maintain compatibility with the current plot design. There is a cost to maintaining this compatibility in that basal area factors could be selected in such a way that trees sampled from the offset microplot can 'grow out' of the sample for a while as they become too large for the microplot sample category but are still too small to be sampled from the sub-plot locus. Calculation and use of the proper joint inclusion probabilities would address this problem; however, its effects would be long term.

An alternative solution (Option 3) would be to sample all trees from the same loci, say the current sub-plot centres. Trees greater than 12.7 cm d.b.h. could be sampled with a pps sample. The seedlings and saplings currently sampled on the microplot could be sampled by (1) a similar microplot relocated to sub-plot centre or (2) a pps sample from sub-plot centre. This third option would require an overlay of the current and new designs for the microplot sample during the first measurement of the new design in order to maintain continuity. Option 3(a) would be very similar to some of FIA's previously used plot designs. Again, as with the variants of Option 2, the variants of Option 3 would not fair as well as Option 1 under a continuity criterion.

As mentioned earlier, the FIA program has had an ever-expanding mission, which has a tendency to cause a re-evaluation of measures of success. Because the diameter distribution has historically been viewed as a basic mensurational variable, its successful estimation has been a goal in forest inventories. If this was solely due to its relationship to wood volume, then some might argue that its adequate description has decreased in value in light of the aforementioned expanding mission of FIA. Quite to the contrary, both biomass and carbon content are also strongly correlated with basal area. It is true that very few quantitative variables, in combination with the species distribution, could tell us as much about the forest (including the ecological structure of the forest) as the diameter distribution. Given that, it seems that any national forest inventory program should place a strong emphasis on its ability to estimate accurately species-specific diameter distributions over appropriately scaled areas of interest. All of the options that we have described above will contribute to an improved estimation of the diameter distribution for FIA, while placing differing emphasis on the balance between sampling efficiency and monitoring continuity.

Conflict of Interest Statement:

None declared.

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