EVALUATION OF MULTIPLE FIXED AREA PLOT SIZES AND BAFS IN EVEN-AGED HARDWOOD STANDS

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ABSTRACT.—A test that utilized fixed area plot size and basal area factor as a continuous variable to determine the relationship with stems (TPA), basal area (BAAC) and board foot volume per acre (BFAC) was applied to even-aged mature (70-year-old) and immature (12-year-old) hardwood stands located in northern West Virginia. For the 70-year-old hardwood sites TPA, BAAC, and BFAC decreased with increasing plot size and converged for fixed area plot sizes greater than 0.08 acre. For BAFs between 10 and 40 these variables increased in a linear fashion with BAF and did not converge. The coefficient of variation (CV) for TPA and BAAC were very similar and less than that for BFAC over the range of fixed area plot sizes and BAFs examined. The CV for all variables decreased with increasing plot size and increased with increasing BAF. In the 12-year-old stands, TPA and BAAC decreased with increasing plot size and converged for plot sizes larger than 0.06 acre. These variables decreased in a linear fashion with increasing BAF between BAFs of 1 and 40 and did not converge. The CV for BAAC was larger than that for TPA in the fixed area plot sizes tested while the reverse was found to be true for point sampling.

Early forest inventory techniques in the United States were based on the use of fixed area sampling units, typically 0.20 and 0.25 acre in size. Fixed area sampling units were the status quo for many years until Grosenbaugh introduced the concept of point sampling in early 1950's. This sampling system changed the way foresters inventoried forest populations fueled primarily by the obvious time savings associated with this technique. Early tests by Grosenbaugh and Stover (1957) in Texas showed that using a BAF of 10 did not differ statistically from estimates based on 0.25 acre and 0.20 acre plots. Though not widely accepted at the time, Husch (1955) and Clutter (1957) tested a limited number of BAFs and found that average per-acre estimates of basal area increased with increasing BAFs. Only the larger BAFs appeared to give unbiased estimates. Zeide and Troxell (1979) cite several references where small BAFs resulted in underestimation of basal area that they concluded was due to missing in-trees. The main reasons given for this apparent anomaly included the existence of heavy understory, poor light conditions, hidden trees and miscounting trees when the number of in-trees was large. In a test of BAF 5, 10, 20, and 40 in a 70-year-old Appalachian hardwood forest in northern West Virginia, Wiant et al. (1984) found that both basal area per acre and board foot volume per acre increased with increasing BAF. Their test results were compared with repeated sampling of this tract using 0.10 acre plots. Both BAF 5 and BAF 10 estimates of volume were statistically less than the estimates using BAF 20, BAF 40 and 0.10 acre plots. They recommend using BAFs of 20 or 40 for sawtimber cruises in this region. During the last decade, foresters have slowly migrated to using a BAF of 20 in sawtimber inventories spurred by the empirical evidence that it provides less biased estimates of stand volume but more likely due to the fact that fewer in-trees would be measured thus saving field data collection time. During this same period the use of 0.10 acre fixed area circular plots also became the norm, although it is not employed as frequently as point sampling techniques.

Methods

Two Appalachian hardwood sites were selected from the Eastern Allegheny Plateau and Mountains land resource region (USDA SCS 1981) and are located in Monongalia and Preston counties, in northern West Virginia. The first location (Mature Hardwood Sites) consists of 40 plots located in 70-year-old even-aged mixed hardwood stands. These plots represent permanent sample plots distributed across both mixed oak and mesophytic hardwood sites (SAF cover types 52 and 59)(Eyre 1980). The individual plots in this site are fairly uniform with a coefficient of variation ranging from 0.31 to 0.51 for trees per acre and board foot volume per acre, respectively (Table 1). The second location (Young Hardwood Sites) consists of 18 plots established in 12-year-old even-aged stands situated on a middle slope having a northwest aspect. Plots on this site are very uniform with a coefficient of variation of 0.22 for trees per acre and 0.14 for basal area per acre (Table 1).

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Table 1.—Descriptive statistics for the mature and young hardwood study sites.

	Mature Hardwood Sites[1]				Young Hardwood Sites[2]			
	Min	Max	Mean	CV	Min	Max	Mean	CV
TPA	10.0	110.0	72.2	0.31	1,690.0	3,960.0	2,773.3	0.22
BA	9.4	187.4	112.4	0.3651.3	88.2	75.4	0.14	
BF	1,173.8	33,885.5	16,482.7	0.51				
QMD	13.2	20.6	16.7	0.101.7	2.9	2.3	0.14	

[1]based on a fixed area plot size of 0.2 acre
[2]based on a fixed area plot size of 0.1 acre

Mature Hardwood Sites

Forty permanent plots were visited and every tree within a 70-foot radius of plot center was measured for dbh, sawlog merchantable height, and distance from plot center. The distance from plot center to each tree was determined using an Impulse 200 laser hypsometer by shooting to a reflective target positioned at dbh and facing the plot center. The distance to the pith was determined by adding half the dbh in feet as determined with a diameter tape. This distance was recorded to the nearest 0.01 foot. Tree dbh was measured with a steel diameter tape and recorded to the nearest 0.1 inch. Since this study involves sawtimber products, only those trees 11.6 inches dbh and larger were included in the analysis. Merchantable height of the sawlog potion of the tree was measured using an Impulse 200 laser hypsometer and recorded to the nearest foot. Sawlog merchantable height was defined as height to an 8-inch dob top or where branching or form limited merchantability for this product. Merchantable height data were collected to estimate board foot contents of each stem using equations published by Scott (1979). Since these plots are centered at an existing square 0.2 acre permanent sample plot, most trees tallied were previously tagged. Once the tagged trees were identified and measured, a sweep of the area for sawtimber trees outside the existing plot but within the 70 foot radius were identified and measured making it quite unlikely that any trees were missed. At each plot, TPA, BAAC and BFAC (Int ¼) were determined for fixed area plots ranging in size from 0.01 to 0.30 acre in 0.01 acre intervals. In addition, the same estimates were made using BAFs from 1 to 50 in 1 BAF intervals. For this study, any tree whose distance from plot center was less than or equal to the limiting distance for that specific sampling unit was included in the tally.

Young Hardwood Sites

Eighteen 0.10 acre circular plots were established in 12-year-old even-aged stands. Every tree taller than 4.5 feet and within a 37.24-foot radius of plot center was measured for dbh and distance from plot center. Tree measurements were conducted using the same procedures used for trees in the Mature Hardwood Sites. At each plot, TPA and BAAC were determined for fixed area plots ranging in size from 0.01 to 0.10 acre in 0.01 acre intervals. In addition, the same estimates were made using BAFs from 1 to 40, in 1 BAF intervals. As with the Mature Hardwood Sites, any tree whose distance from plot center was less than or equal to the limiting distance for that specific sampling unit was included in the tally. Plot data were summarized for each fixed area plot size and BAF examined. Mean trees and basal area per acre as well as the coefficient of variation and the average number of in-trees were determined for this sample of 18 plots.

Results

Mature Hardwood Sites

Figure 1 depicts the mean TPA, BAAC, BFAC, number of in-trees, and coefficient of variation for TPA, BAAC and BFAC for the 40 permanent sample plots described previously. Mean BFAC decreased with plot size but stabilized for fixed area plot sizes greater than 0.08 acre. The small variations in volume per acre for plot sizes from 0.10 to 0.26 acre are most likely due to spatial variation of trees among the different plot sizes. The coefficient of variation for BFAC decreased with increasing plot size but only changed 10 percentage points (0.6 to 0.5) between plot sizes of 0.13 to 0.30 acre. A similar pattern is portrayed for estimates of TPA. Trees per acre stabilized for plot sizes larger than 0.09 acre. The coefficient of variation stabilized for plot sizes larger than 0.06 acre. As expected, the graph of BAAC by plot size is very similar to that of BFAC. The average number of in-trees per plot increased linearly with increasing plot size from 1

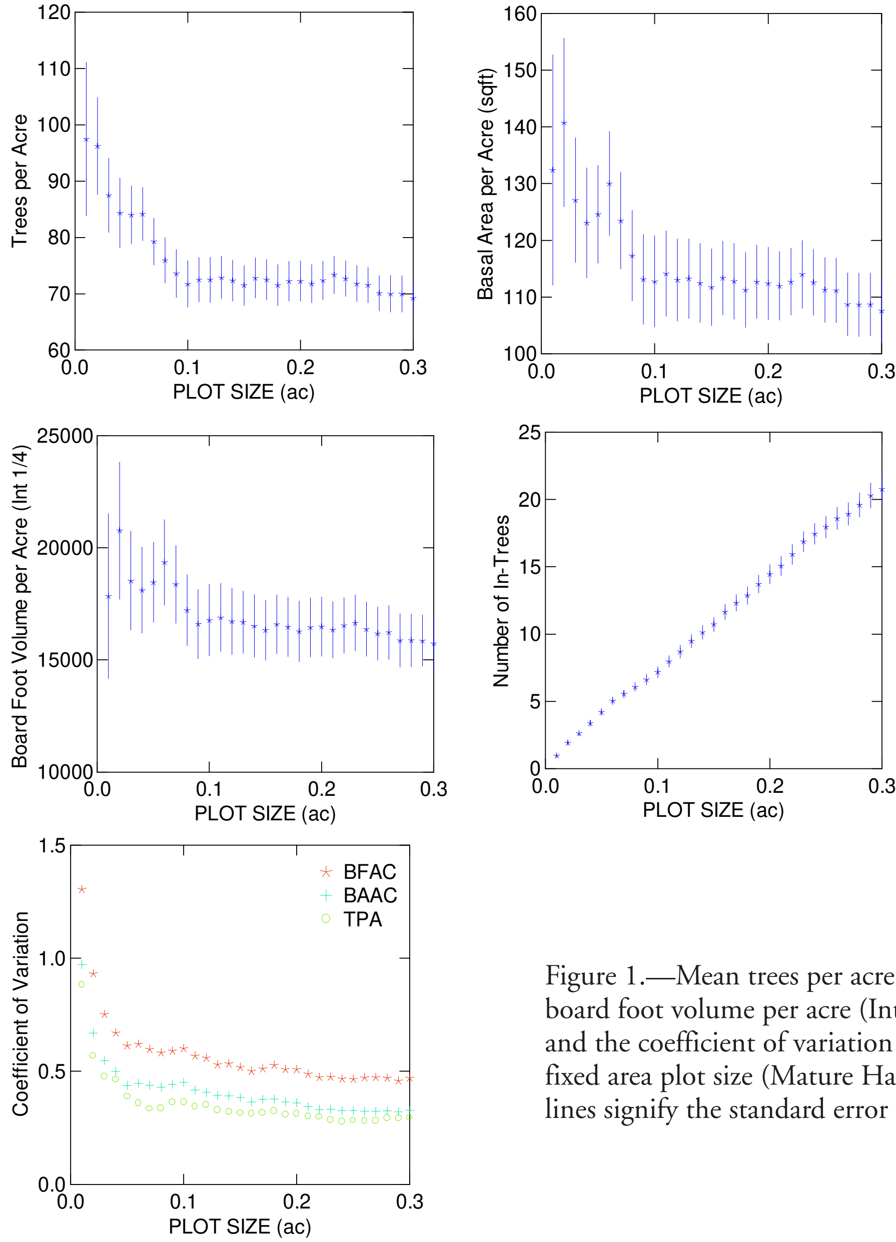

Figure 1.—Mean trees per acre, basal area per acre, board foot volume per acre (Int ¼), number of in-trees and the coefficient of variation by stand parameter by fixed area plot size (Mature Hardwood Sites). Vertical lines signify the standard error of the mean.

tree (0.01-acre plot) to 19 trees (0.30-acre plot). The vertical lines depicted in Figure 1 signify the standard error of the mean for that sample size. A SAS General Linear Models test was conducted to determine whether the means for TPA, BAAC or BFAC were the same for all plot sizes ($\alpha = 0.05$). Only TPA indicated significantly different means. A mean separation test (Tukey) was unable to identify differences in mean TPA.

As mentioned previously, BAF was increased in units of 1 BAF starting with a BAF of 10 and culminating with a BAF of 50. Based on previous work in this region, it is realistic to believe that an appropriate BAF would fall within this range. Figure 2 shows the mean TPA, BAAC, BFAC, number of in-trees, and coefficient of variation for TPA, BAAC and BFAC with increasing BAF. The pattern shown in Figure 2 is typical of the pattern described by Wiant et al. (1984) as well as other investigators, but in this case it is very unlikely that this anomaly can be explained by missing in-trees. The irregular pattern shown between BAF 40 and 50 is currently unexplained. The coefficient of variation for BFAC increased with increasing BAF from 0.48 (BAF 10) to 0.69 (BAF 50). However, this increase is relatively small between BAF 13 and 30. The estimates for TPA increased in a consistent manner from BAF 15 to BAF 40, after which there is an unexplained drop in TPA. The coefficient of variation for TPA increased linearly with increasing BAF

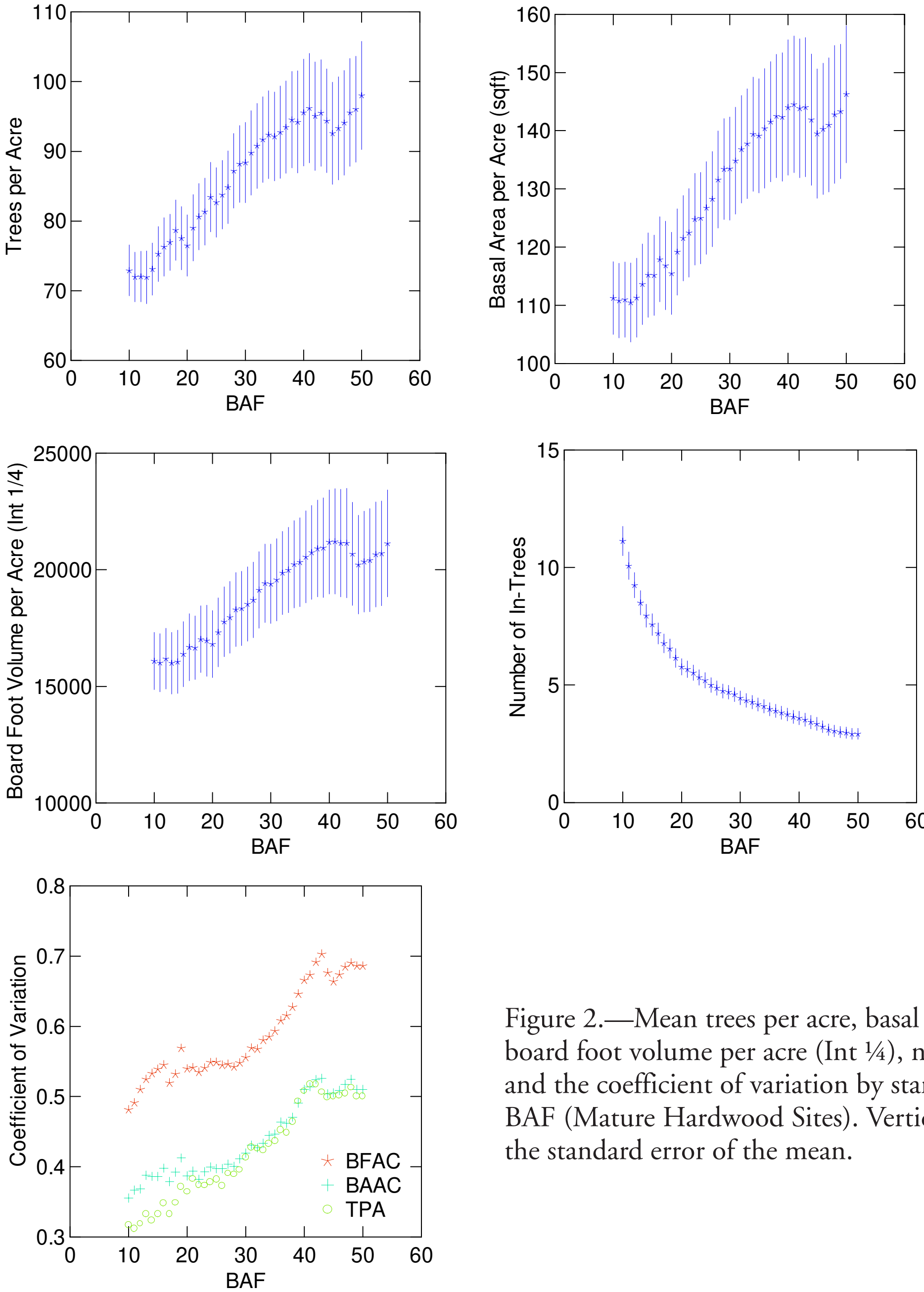

Figure 2.—Mean trees per acre, basal area per acre, board foot volume per acre (Int ¼), number of in-trees and the coefficient of variation by stand parameter by BAF (Mature Hardwood Sites). Vertical lines signify the standard error of the mean.

up to a BAF of 40. There seems to be very little increase in variation above a BAF of 40. As with fixed area plot samples, BAAC followed a similar trend to BFAC. The mean number of in-trees per point decreased exponentially with increasing BAF with an average of 11.1 in-trees with BAF 10 and approximately 3 in-trees for BAF 50. A SAS General Linear Models test was conducted to determine whether the means for TPA, BAAC or BFAC were the same for all BAFs ($\alpha = 0.05$). Only BAAC and TPA indicated significantly different means. A mean separation test (Tukey) was unable to identify differences in either mean BAAC or TPA.

Young Hardwood Sites

Figure 3 depicts the mean TPA, BAAC, number of in-trees and the coefficient of variation for TPA and BAAC with increasing plot size. Although these estimates are based on fewer plots (18), BAAC and TPA appear to stabilize above a fixed area plot size of 0.06 acre. The number of in-trees required for each plot size increases linearly ranging from 10 (0.01-acre plot) to nearly 300 (0.10-acre plot). The mean number of

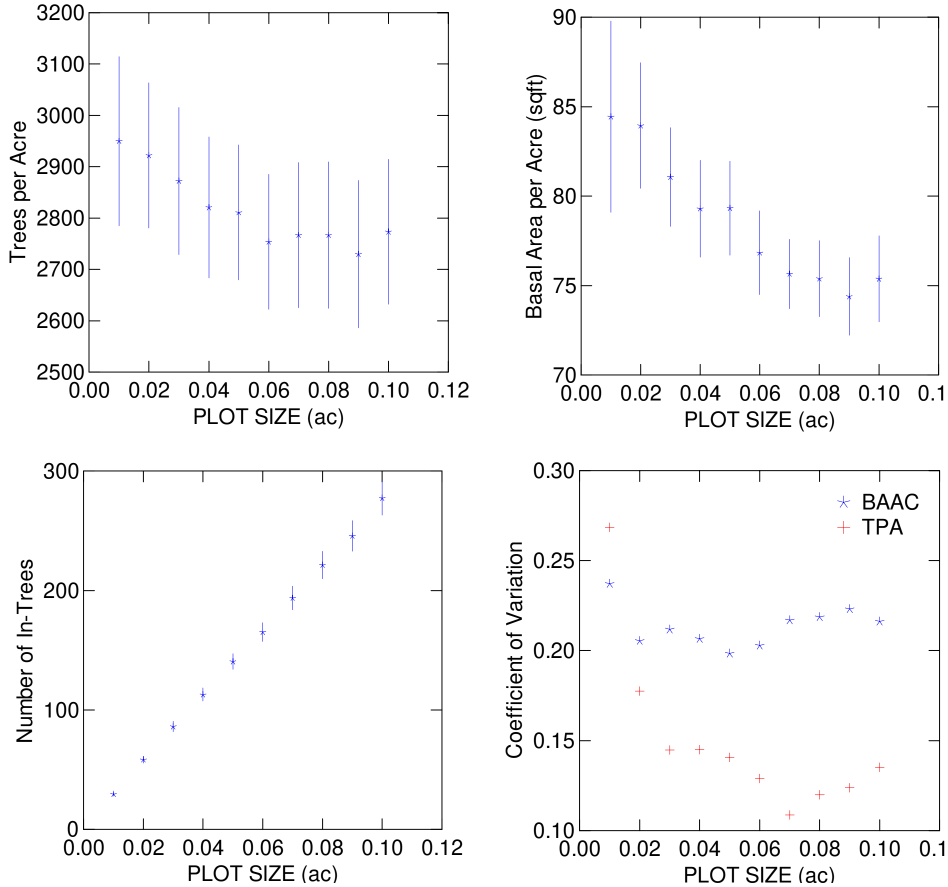

Figure 3.—Mean trees per acre, basal area per acre, number of in-trees and the coefficient of variation by stand parameter by fixed area plot size (Young Hardwood Sites). Vertical lines signify the standard error of the mean.

in-trees for a 0.06 acre plot was approximate 150 trees. No significant differences between sample means were found for BAAC or TPA.

The results obtained using point sampling are exactly opposite that found for the Mature Hardwood Sites. In this situation, BAAC decreased with increasing BAF (fig. 4). The same relationship was observed for the mean TPA. As was found with point sampling in the Mature Hardwood Sites, the number of in-trees decreased exponentially with increasing BAF ranging from 75 (BAF 1) to 1 (BAF 40). No significant differences were found between sample means.

A review of the coefficient of variation by plot size and BAF indicated that TPA is more variable than BAAC for point sampling but not for fixed area plots. These values stabilize relatively quickly in small fixed area plots and do not stabilize at all for different BAFs.

Conclusions

The effect of increasing plot size and BAF on BFAC, BAAC and TPA was examined on age 70 (Mature Hardwood Sites) and age 12 (Young Hardwood Sites) even-aged hardwood sites in northern West Virginia. Statistically significant differences were found for BAAC and TPA for the range of BAFs examined. For the range of fixed area plot sizes tested, only TPA showed a significant plot size effect. Mean separation tests (Tukey) were unable to identify significantly different means. On the Mature Hardwood Sites, average BFAC stabilized for fixed area plot sizes larger than 0.08 acre. Utilizing the same plot centers, board foot

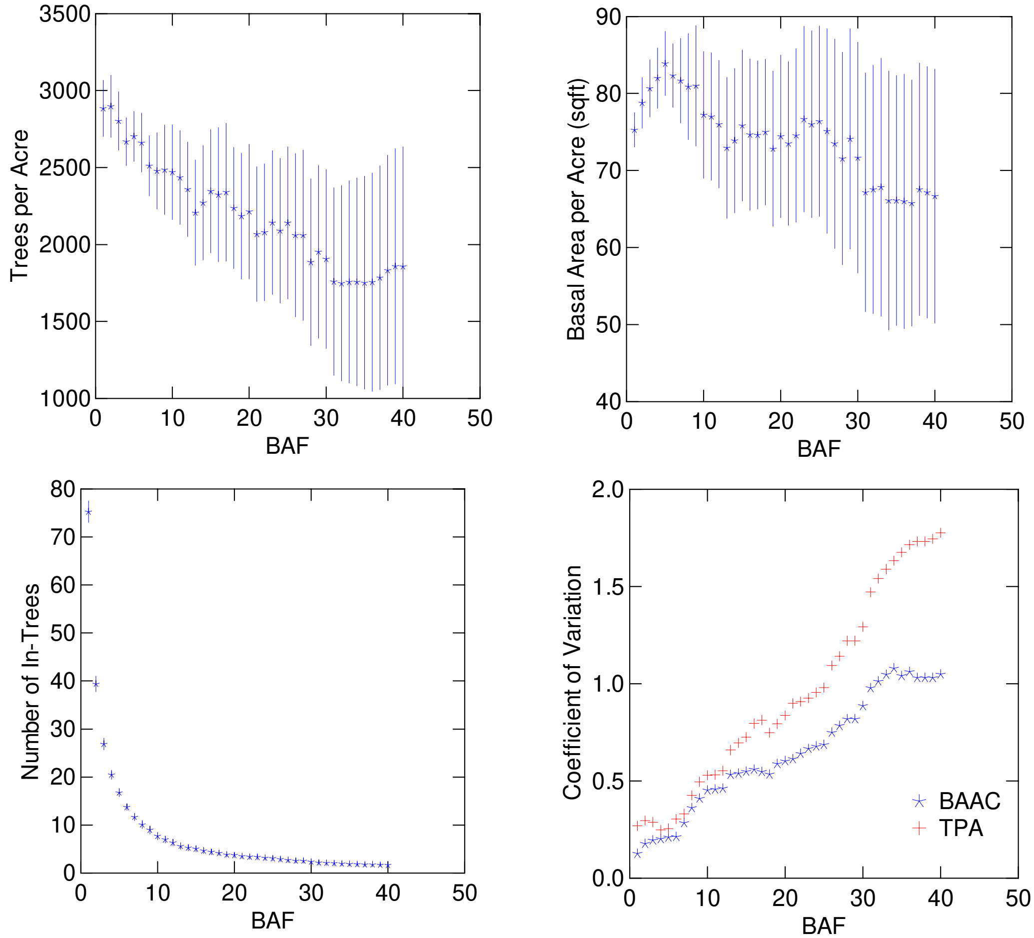

Figure 4.—Mean trees per acre, basal area per acre, number of in-trees and the coefficient of variation by stand parameter by BAF (Young Hardwood Sites). Vertical lines signify the standard error of the mean.

volume increased linearly with increasing BAFs between 10 and 40. These results support the findings of earlier investigators (Clutter 1957, Zeide and Troxell 1979, Wiant et al. 1984) but it is unlikely that the results are due to missing in-trees, thus indicating a bias associated with the implementation of point sampling on these sites. If one would assume that the "true" value for the parameter of interest is identified by the values from the fixed area plot graphs where the means flatten out and become less variable, then an estimate of the "true" board foot volume per acre is around 15,500 bf/ac and the "true" basal area per acre is approximately 105 ft^2/ac. This would indicate that the appropriate BAF to use would be between 16 and 20 for board foot volume and basal area per acre. Either of these situations would require less than 7 in-trees per point, on average. It is interesting to note that if the "true" volume is as described above, selection of a BAF of 40 would have resulted in an overestimation of volume by 26 percent. The coefficient of variation for BFAC was larger than that for BAAC or TPA for the fixed area plot sizes and the different BAFs examined. Additional study is recommended as an increase in sample size would likely result in an increased ability to distinguish significant differences between sample means.

Less prior work has been done regarding the appropriate plot size or BAF to use when sampling immature stands, due primarily to their lower inherent value. In general, foresters have employed smaller plot sizes in younger stands, though the reasoning may be more related to practicality than in selecting an unbiased estimate of the variable of interest. In this relatively small sample, no statistical difference was found between the means for BAAC or TPA for the range of BAFs and fixed area plot sizes examined. Average basal area and trees per acre stabilized in fixed area plot sizes larger than 0.06 acre. However, the average number of in-trees at this plot size is approximately 150. In general, mean BAAC and TPA decrease with increasing BAF in these stands. It is the same phenomenon obtained with the Mature Hardwood Sites, but with a negative slope. Again, if one would assume that the "true" value for the parameter of interest is identified by the values from the fixed area plot graphs where the means flatten out and become less variable, then an estimate of the "true" basal area per acre is around 75 ft^2/ac and the "true" trees per acre is approximately 2,750. This would indicate that the appropriate BAF to use would be between 10 and 27 for BAAC and 3 and 6 for TPA. Either of these situations would require less than 20 in-trees per point, a value much lower than that needed for fixed area plots. For the fixed area plots examined, the coefficient of variation for BAAC was larger than that for TPA. The exact opposite was found for the BAFs tested. Additional investigation is needed in immature hardwood stands to determine whether these relationships hold over larger sample sizes and different site types. Care must be taken in selecting an appropriate BAF in any age stand as the variable of interest has been found to change linearly with BAF in all sites examined.

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