
Comparative Evaluation of Accuracy and Efficiency of Six Forest Sampling Methods

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We compared estimates of woody stem density with known stem densities in three forest stands in southeast Oklahoma by using fixed-radius plots 3.64 m radius (0.01 acre; FRPs-AC), fixed-radius plots 5.64 m radius (0.01 ha; FRPs-HA); 10 m X 10 m quadrat (0.01 ha; QUAD), variable-radius plot (VRP), point-centered quarter (PCQ), and belt transect (BT) sampling techniques. These stands varied in stem density and were categorized as high, moderate, and low density stands. We found that FRPs were the most time-efficient and produced the most accurate estimates regardless of stem size. The VRP and PCQ methods were also time-efficient, but tended to underestimate actual stem density. Although FRPs of suitable size are accurate for large diameter stems in dense forest, time constraints limit applicability. We recommend using FRPs for small stems [(2.54–11.42 cm diameter breast height (DBH))] and VRPs for large stems (≥ 11.43 cm DBH). These methods with appropriate sample sizes should be applied after pre-sampling has been completed to determine sampling variance. This combination of methodologies provides a quick and relatively accurate manner to characterize or monitor change in the wide range of forest conditions found in Oklahoma. ©2002 Oklahoma Academy of Science

INTRODUCTION

Quantitative data are essential to adequately characterize the woody component of forest communities (1,2). Some form of sampling is required because total counts of individuals in naturally occurring plant populations are generally impractical without an exhaustive expenditure of energy and resources (3). A number of sampling techniques are available to quantify forest communities. These techniques vary in quantitative capabilities, equipment required, and time necessary to obtain an adequate sample for statistical analysis (4,5). Obtaining adequate information with minimum effort and time is a major concern when sampling vegetation (4,5).

Variable radius plot (VRP), fixed radius plot (FRP), point-centered quarter (PCQ), belt transect (BT), and 10 m X 10 m plots (QUAD) are sampling methods commonly used to quantify forest vegetation (2–6). The purpose of this study was to determine the best sampling method for use in widely varying forest conditions that would adequately characterize forest communities in Oklahoma for the purpose of monitoring change in the woody component following either experimental manipulation or land use change. Our primary objective was to compare the accuracy of estimates of woody stem density for six forest sampling techniques under widely varying stand densities. A second objective was to compare

the time required by these methods to obtain a 10% sample (by area).

STUDY AREA

We conducted this study on the Pushmataha Forest Habitat Research Area (PFHRA) on the 7395 ha Pushmataha Wildlife Management Area, approximately 6 km southeast of Clayton, Oklahoma (7). The PFHRA was protected from logging, grazing, and fire until 1984 when a comprehensive study on the effects of fire and timber harvest began (7–10).

We selected three different stands in the research area to represent varying stand densities in both understory and overstory. Stands included

1. High density stand—unmanaged stand, no fire or timber harvest, 0.92 ha in size.
2. Moderate density stand—removal of 1/2 of the hardwood basal area, annual winter burn since 1985, 0.56 ha in size.
3. Low density stand—harvest all merchantable pine, annual winter burn since 1985, 1 ha in size.

The high density stand was dominated by post oak (*Quercus stellata*), shortleaf pine (*Pinus echinata*), with occasional blackjack oaks (*Q. marilandica*) and mockernut hickory (*Carya tomentosa*) (7). Shortleaf pine dominated the moderate density stand while the low density stand was dominated by post oak with occasional blackjack oak and mockernut hickory. Study area soils and vegetation on these sites were previously described by Masters and Masters et al. (7–10).

METHODS

We delineated the area to be sampled in each stand by using a compass and hip chain. We sampled experimental stands ≥ 20 m from stand boundaries to minimize edge effects from adjacent stands. After stand boundaries were surveyed and marked, we obtained a total count of stem density from each stand. We recorded species and diameter at breast height (DBH) of all stems with a DBH ≥ 2.54 cm. After a stem was

tallied we marked the bark or foliage with paint to ensure that all trees were counted accurately.

We selected sampling points at random distances along a base line through the long axis of the stand after the method of Beason and Haucke (3). We then selected a random distance from the random point on the base line for location of plot center. This process continued until the desired number of samples had been taken (Table 1).

Sampling Methods: The six sampling methods compared with total census counts included VRPs, 3.64 m fixed-radius plot (FRP-AC), 5.64 m fixed-radius plot (0.01 ha; FRP-HA), QUAD, PCQ, and BT. We practiced each sampling method prior to sampling to familiarize ourselves with the methods. We performed only one sampling technique on a plot at a time. Sampling time was recorded with a stopwatch.

We sampled approximately 10% of the area of each experimental unit using all methods except VRP. For VRP, we used the same plot centers as those used in the PCQ method. We tallied all woody species with a DBH ≥ 2.54 cm, except when applying the PCQ, for which only stems ≥ 11.43 cm were tallied. We recorded species and DBH for all sampling methods.

We counted all stems of appropriate DBH in a given area for the FRP-AC, FRP-HA, QUAD, and BT. We used a 10-factor prism when applying the VRP method (2, 11, 12). We tallied trees that subtended an angle equal to or greater than that of the prism.

When using the PCQ method we divided sampling points into four quarters (3, 4). In each quarter we tallied the nearest tree ≥ 11.43 cm. We did not sample small stems when using the PCQ method. We then measured from the sample point to the nearest tree in each quarter (quadrant) and recorded this measurement. We placed BTs on randomly located lines running the length of the stand by using a transect width of 1 m (Table 1). We tallied all trees within the 1 m transect width and tallied every other border-line tree.

Data Analysis: To facilitate comparison, density estimates were summarized on a hectare basis. Stems were classified into two size classes for analysis: 2.54 to 11.42 cm and ≥ 11.43 cm. A difference value was obtained by subtracting actual stems/ha from estimated stems/ha. Chi-square analysis was used to determine the accuracy of sampling methods ($P < 0.05$; 13). We also analyzed the data as a randomized complete block design (ANOVA) with stands as the block and sampling technique as the treatments to determine if mean density estimates were different between techniques. Technique means were separated with the protected least significant difference (LSD) test (14).

RESULTS

As expected, we found wide variation among sample plot estimates within a given technique by stand density. Therefore, we were not able to detect a significant difference in density estimates between sampling techniques by using the LSD test ($P > 0.05$). We found that technique performance was apparently dependent on the size class and distribution of woody stems in a given

stand. We did detect differences in accuracy using chi-square analysis.

Stems 2.54 to 11.42 cm: The FRP-AC and FRP-HA methods were accurate in the high density stand ($\chi^2 = 0.11$ and 0.01 , respectively, $P < 0.05$; Fig. 1). Both FRP methods underestimated stem density on less dense stands (Fig. 1). The QUAD method was not accurate and underestimated density in both high and moderate density stands, but did produce reasonable estimates in low density stands. The VRP method produced varied estimates across all three levels of stem density and was judged to be unsuitable for small stems (Fig. 1). The BT technique produced more accurate results at low densities than at moderate and high densities (Fig. 1).

Stems ≥ 11.43 cm: The FRP-AC and QUAD produced accurate ($\chi^2 = 3.20$ and 1.60 , respectively, $P < 0.05$) estimates of stem density in high density stands (Fig. 2). The BT was somewhat accurate for high density stands ($\chi^2 = 4.10$, $P < 0.10$). The QUAD and BT methods produced accurate ($\chi^2 = 1.50$ and 2.30 , respectively, $P < 0.05$) estimates at

TABLE 1. Total time (minutes) required to sample approximately 10% of a hectare using various sampling techniques on Pushmataha Forest Habitat Research Area, Summer 1994.

Stem Size-Class, Technique ^a	Stand Density		
	High	Moderate	Low
Stems 2.54-11.42 cm			
FRP-AC ^b	50	30	20
FRP-HA	55	34	25
QUAD	63	44	41
BT	144	99	86
Stems ≥ 11.43 cm			
PCQ	235	104	47
All stems			
FRP-AC	160	145	137
VRP	72	47	34
BT	327	225	195

^a FRP-AC = fixed-radius plot, 3.64 m radius (0.01 acre); FRP-HA = fixed radius plot, 5.64 m (0.01 ha); QUAD = 10 m X 10 m quadrat, (0.01 ha); VRP = variable-radius plot; BT = belt transect; PCQ = point-center-quarter.

^b These times for this technique were relative estimates because all stem size classes were counted when applying this technique.

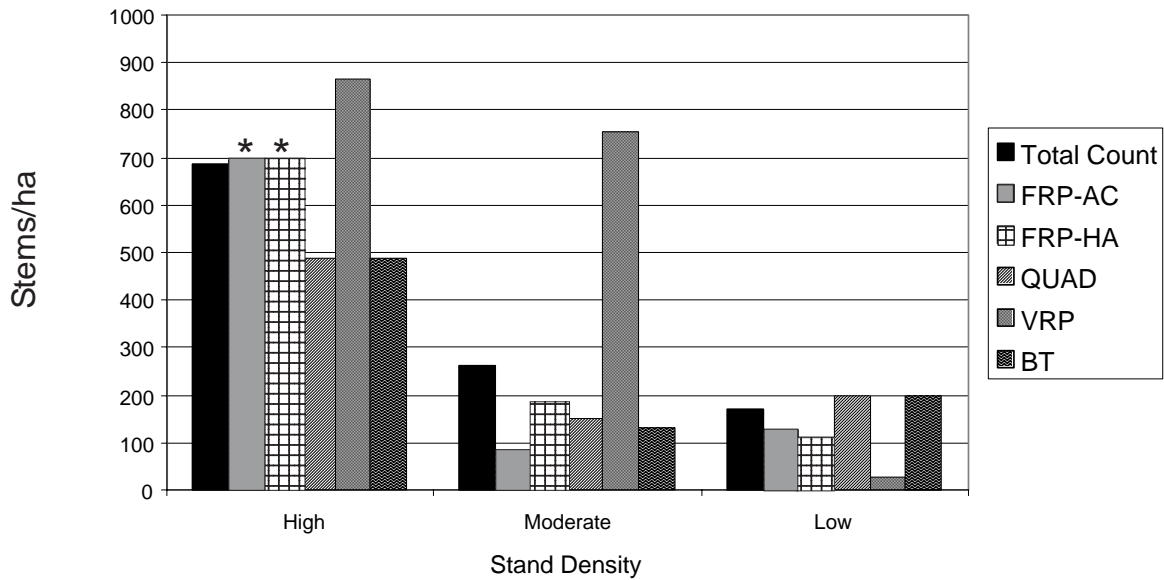


Figure 1. Comparison of five forest sampling techniques for stems 2.54 - 11.42 cm in diameter, in high-density, moderate-density, and low-density stands on Pushmataha Forest Habitat Research Area, summer, 1994. FRP-AC = fixed-radius plot, 3.64 m radius (0.01 acre); FRP-HA = fixed radius plot, 5.64 m (0.01 ha); QUAD = 10 m X 10 m quadrat (0.01 ha); VRP = variable-radius plot; BT = belt transect; PCQ = point-centered quarter. Those bars with an * were significantly accurate ($P < 0.05$) using the chi square test.

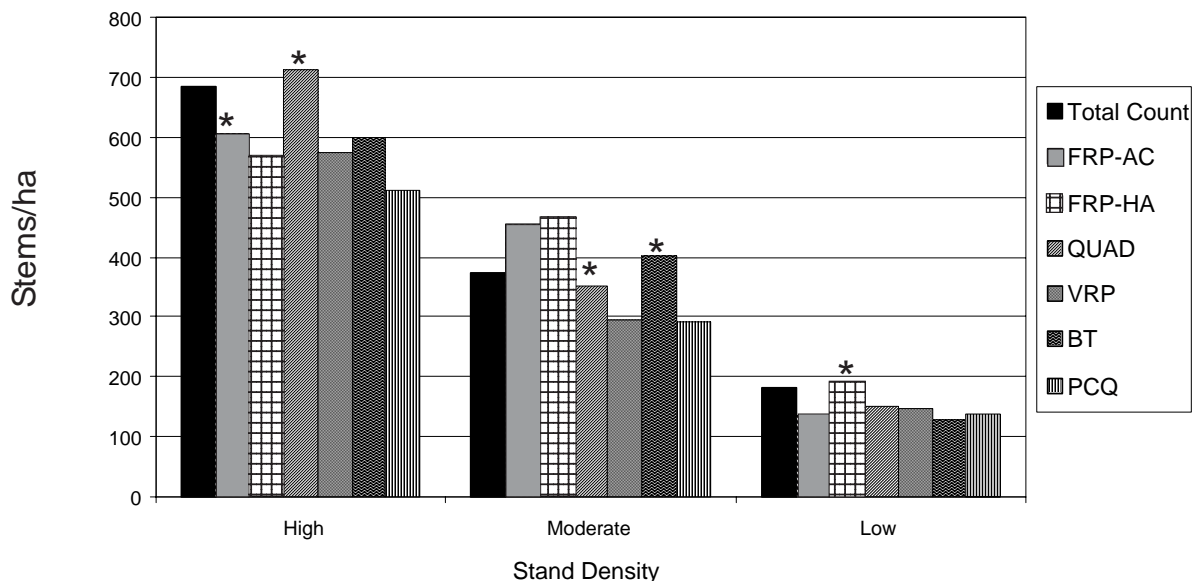


Figure 2. Comparison of six forest sampling techniques for stems ≥ 11.43 cm in diameter, in high density, moderate density, and low density stands on Pushmataha Forest Habitat Research Area, summer, 1994. FRP-AC = fixed-radius plot, 3.64 m radius (0.01 acre); FRP-HA = fixed radius plot, 5.64 m (0.01 ha); QUAD = 10 m X 10 m quadrat (0.01 ha); VRP = variable-radius plot; BT = belt transect; PCQ = point-centered quarter. Those bars with an * were significantly accurate ($P < 0.05$) using the chi square test.

moderate stem densities, and the FRP-HA produced accurate ($\chi^2 = 0.80$, $P < 0.05$) results in the low density stand (Fig. 2). The QUAD technique produced estimates within 26 stems of the actual, across all stands (Fig. 2). The PCQ and VRP methods underestimated stem densities in all three stands, but the difference was proportional and constant across all stand densities (Fig. 2).

Sampling Time: The FRP-AC was the fastest method applied, closely followed by the FRP-HA and QUAD methods for small diameter stems (Table 1). The BT was much slower because of setup time needed to apply this method. The PCQ method was not directly comparable to other methods because we used it for estimating larger diameter trees. It performed more time efficiently in stands with low density, but was much slower in stands with high densities (Table 1). The VRP method was the most rapid of all techniques to sample all stem size-classes. The BT method was the slowest technique, taking more than twice the time of other methods (Table 1).

DISCUSSION

Sampling Accuracy: Vegetation is often clumped or patchy in distribution (5). The high standard deviation we found associated with mean estimates derived from these sampling methods reflects the clumped and patchy distribution of trees within these stands. Four of the seven accurate estimates were from sampling techniques applied in the high density stand. Density estimates from the various sampling techniques in the high density stand were generally more accurate because our observations were that stems tended to be more evenly distributed. Stems in the moderate and low density stands tended to be clumped and patchy in distribution in violation of the statistical assumption that stems were randomly distributed. In situations with nonrandom distributions, sampling intensity must be increased until the variance is lowered rather than going with a set 10% minimum level sample.

VRPs and FRPs are unbiased for all distributions but distance measures are not

(6, 15, 16). Any biases found in estimates may be related to field technique or may be attributable to stand conditions such as poor visibility in dense stands and bias arising when determining if a tree should be tallied when using the VRP method. This is particularly problematic when making determinations with a prism for small diameter stems close to the sampling point in dense stands (6). This was apparent in widely varying estimates of stems < 11.43 cm derived by the VRP method in different density stands. However, we found that the VRP consistently underestimated density for larger stems.

FRPs (circular) were indeed accurate and unbiased at high stem densities, but variation increased between samples when applied to the lower density stands. Under these conditions sampling intensity must be increased and pre-sampling with attention to variance estimates should increase confidence in the estimates.

Sampling and Time Efficiency: The techniques that performed best for sampling stems < 11.43 cm across different density stands included the FRP methods of different size. The FRP-AC was relatively time-efficient and produced excellent results regardless of stem size in the high density stand. However, it produced estimates of poor accuracy in our sparse stand. An advantage of this method is its ability to be applied to all stems regardless of size. The only problem with the method is that it requires more samples to obtain the same sampling intensity as other methods. The FRP-HA has the same advantages and produced similar results to those of the FRP-AC method, but has the additional advantage of sampling a larger area, therefore, requiring fewer samples than the FRP-AC to obtain the same sampling intensity.

All methods used to sample stems ≥ 11.43 cm produced relatively accurate estimates in the high density stand and may be attributed to the relatively high stem density and even distribution of stems in this stand. The QUAD method consistently produced the most efficient results for sampling larger stems (≥ 11.43 cm), except for the low density stand. The QUAD

method can also be used to sample all stems in an area regardless of size, but produced less accurate estimates than those of the FRP-AC or FRP-HA methods when sampling small stems. However, the QUAD provided more accurate estimates of larger stems than did both FRP methods. The QUAD tended to be less time-efficient than the FRP methods and required the use of a transit and tape measure for accurate plot layout or a large sampling quadrat, which can be cumbersome to transport and set up in dense stands. The QUAD method requires considerable care so that stems are not counted twice.

Although the VRP method was one of the fastest methods, its use should be limited to primarily larger stems with a DBH ≥ 11.43 cm. The VRP method produced poor and wide ranging accuracies on smaller stems (< 11.43 cm), overestimating dense stands and underestimating low-density stands. The VRP also tended to underestimate overall stem density of stems ≥ 11.43 cm, but estimates were a consistent percent difference across all stand densities and may be reduced if additional samples were taken.

The BT produced poor estimates on small stems, but relatively accurate estimates on larger stems. Although it can be used to sample all stems regardless of size, this method was not very time-efficient, primarily because transects must be set up and measured before sampling can begin. This method would be best suited to long transects, with the aid of a compass and a device to measure distance traveled. The BT method may be best applied in transition zones or gradients where the vegetation changes in composition and density (6).

The PCQ method was quite time-efficient, but was applied only to larger stems. The PCQ method tended to underestimate actual stem density in all stands, but like the VRP, the PCQ method also maintained a consistent percent difference in observed versus estimated stem densities across all stands regardless of overall stem density. That distance techniques may give biased estimates, depending on tree spatial distributions, is an inherent disadvantage.

Shape: FRPs with a circular shape tended to produce the most accurate results on smaller stems (2.54 to 11.42 cm), especially when applied in dense, evenly distributed stands. This can be attributed to the small perimeter to area ratio in a circle; therefore, an observer is less likely to have to make a decision to tally a stem or not because it intersects the plot (17). Also, the rotating radius of the plot allows an observer to ensure all stems are tallied and are only tallied once. When using a large quadrat (10 m x 10 m) it is easy to miss stems or to tally them twice (6, 18). The FRP methods or circular-plot sampling methods are quick and simple to apply in areas with low to moderate density of stems or areas with low vegetation, but become awkward in dense, shrubby communities (6, 18). Smaller FRP or square-plot methods can be used in stands with dense vegetation (18).

Size: It is essential for quadrat size to be adapted to the characteristics of the vegetation being sampled (18). The greater the species diversity and the more heterogeneous life forms found in a community, the larger the quadrat size needed to adequately characterize the community (18). Regardless of shape, perimeter to area ratios decrease with an increase in quadrat size (17). Based on the diversity found in many forested communities and on perimeter to area ratios, larger circular plots would be most appropriate (17).

CONCLUSIONS

It is important for managers to know the general characteristics of the stand they are attempting to sample because no single method is efficient for sampling all stem sizes and densities. Sample procedures provide only an estimate, and this estimate may be smaller or greater than actual stem density depending on the sample method applied and stand density. Methods should be chosen that reflect unbiased estimates of density given various stand conditions and distributions.

Circular and fixed area methods, such as the FRP-AC and FRP-HA, were the most

time-efficient and produced the most accurate estimates of all stems in a stand regardless of size. The QUAD produced slightly more accurate estimates of larger stems, but produced less accurate estimates of small stems and was also less time-efficient. The VRP was extremely time-efficient and produced precise estimates of larger stems, but tended to underestimate the actual number of stems. The PCQ method also produced time-efficient and precise estimates of larger stems, but underestimated actual stem density. Furthermore, the PCQ may produce biased estimates depending on stem distribution in a stand. Both the VRP and PCQ produced precise estimates, regardless of stem density; therefore, these methods are usable when the manager takes into account that the estimate obtained may be low. By calculating the appropriate sample size from a preliminary field size, estimates may be closer to the true mean and may reflect unbiased estimates of stem density when applying the VRP method.

We recommend using a combination of an FRP method and VRP method when sampling stems of all sizes in variable-density forested communities. FRP methods provide relatively accurate and time-efficient results on small stems (DBH 2.54-11.42 cm), while the VRP method is time-efficient and relatively accurate at sampling larger stems (DBH \geq 11.43 cm). The number of samples should be based on the standard deviation or coefficient of variation of a preliminary field sample. The combination of these methods will provide accurate and time-efficient results for sampling woody species regardless of size.

ACKNOWLEDGMENTS

Funding was provided through the Oklahoma State University, Department of Forestry and Oklahoma Agricultural Experiment Station. We thank M. Stewart for field assistance and T. Lynch for review of an earlier draft. This article is published with the approval of the Director of the Oklahoma Agricultural Experiment Station.

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Received: May 1, 2002; Accepted: June 24, 2002