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A COMPARISON OF FOREST ECOLOGICAL SAMPLING TECHNIQUES USING A KNOWN POPULATION [1]

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Introduction: Inasmuch as there is increasing recognition of the need for quantitative evaluations of vegetation and concomitantly, an increase in the use of and reliance on quantitative sampling techniques, this study has been undertaken in an attempt to evaluate sampling methods currently employed.

The reasons for sampling vegetation are manifold. The information derived from sampling vegetation may be of a phytosociological nature, or it may be estimates of basal area per acre, number of stems per acre, volume of timber per acre, or estimates of merchantable timber.

Quadrat sampling was the first wide-spread technique used to get quantitative information about plant communities. The information sought was for the most part such quantities as dominance, density, and frequency, and the attempt in each case was to classify the community on the basis of composition and structure. To this end, a variety of quadrats were devised which were first used to sample herbaceous vegetation, and later by merely increasing their size they were used in vegetation sampling.

The chief weakness of quadrat sampling is the difficulty of locating quadrats in the field in some random manner. Unless the area is thoroughly scouted and some provision made for randomization, analysis of sampling error and the assessment of accuracy is complicated if not impossible. Even the use of stratified random sampling techniques poses difficulty for the actual placement of quadrats in the field. Bourdeau (1953) analyzed random versus systematic quadrat sampling utilizing a completely enumerated and mapped area 120 × 120 meters. The area is a portion of the Duke Forest. From his map sampling he concluded ". . . that stratified random sampling should be widely used in ecological work since it will be almost as accurate as systematic sampling, if not more so and it allows a reliable assessment of sampling error, for about the same amount of time involved in the field." Thus, if it is the desire of the investigator

[1] Portion of a dissertation presented to the Graduate School of The Ohio State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy, August, 1954.

to use statistical devices, he must select his samples randomly as a condition of the statistical method.

Secondly, quadrat size has a direct bearing on the results obtained from sampling. Investigators have for the most part settled arbitrarily on the 10-meter quadrat for tree vegetation and the 1-meter quadrat for herbaceous vegetation. The milacre quadrat is used in forestry work. Several other sizes are used but none so frequently as the 10-meter quadrat.

Perhaps the least controversial use of the quadrat is not as a sampling technique but rather as a means of marking off an area to study succession and development in that area. The establishment of permanent quadrats enables the investigator to return to the same location each year and obtain data that can be compared on a year to year basis.

If it is the purpose of the investigator merely to classify the vegetation, that can be done much more simply by thorough inspection than by quadrat sampling. Such quantities as presence, frequency and density cannot be derived by simple inspection inasmuch as these are numerical values intimately associated with quantitative sampling, but dominance can be ascertained by inspection and important as well as associated and secondary species can be evaluated in terms of abundant, common or rare occurrence. These terms can apply to succession as well as to classification (Sampson, 1930, 1930a).

The use of quadrat sampling to estimate quantitative characteristics such as basal area per acre or stems per acre is a different matter, which can be done with less bias than classification. The size, number, and location of the quadrat are still, however, arbitrary decisions to be made by each individual investigator in accordance with his own special desires and the peculiarities of the area under study.

The transect was devised for the study of succession in the transitions between different vegetation types. It was later applied to the quantitative sampling of vegetation. The transect has been deemed by some investigators to be a more efficient technique than the quadrat method for quantitative sampling, especially in the sampling of communities where sizes of individuals vary greatly. The technique differs from quadrat sampling only in that the sample area is of a different size and shape. The principal advantage is that, with transects it is possible to include in one sample a number of differing parts of the community. This in itself is a help and a hindrance. In a naturally heterogenous community it may be desirable to include a variety of parts of the community in one sample, but in a case where two or more communities are interspersed the relationships of the communities may be obscured, or not even recognized.

The lateral area of the transect may be varied from the width of a line to some large dimension, making it useful for either rapid or extensive surveys.

Within recent years, two new plotless sampling methods have been introduced into forest ecology. They are the Random Pairs method of Cottam and Curtis (1949), and the Plotless Variable Radius method of Bitterlich described in the American literature by Grosenbaugh (1952).

The random pairs method was developed as a means of providing quantitative information about the original vegetation and is used currently for that purpose. Curtis and McIntosh (1951) used random pairs sampling in their analysis of Wisconsin forest vegetation which resulted in their proposal of an upland forest continuum in Wisconsin.

The plotless variable radius method was developed in Germany and recently introduced to American investigators. With it, account is taken of size of the trees as well as of their spacing.

Both of these methods are fast and relatively simple to use. Both were worked out primarily to estimate different characteristics of the vegetation. The random pairs method is based on the assumption of equal spacing of trees in an ideal forest. The plotless variable radius method is based on the relationship of the area of tree trunks to the area over which the trees are spaced.

On the basis of the assumptions of each method, one would expect that the random pairs method would yield more accurate estimates of stems per acre and that the plotless variable radius method would yield more accurate estimates of basal area per acre.

An unstated implication of all these sampling techniques is that they be applied to undisturbed or relatively undisturbed vegetation, and further that the vegetation sampled be fairly uniform. None of them contain inherent provisions for the discovery of the effects of natural or man-made physical catastrophes. With them the condition of the vegetation can not be evaluated, except by reference to known vegetation types and known processes of vegetation change. Sampling as a device should be used only to ascertain quantitative information about vegetation whose qualitative characteristics are known. As such it can become a valuable tool for the comparisons of examples of the same vegetation type separated in space. It may also be used to evaluate deviations from either an ideal or reference vegetation type brought about by known causes.

Description of Area and Method: The field data for this study were collected at Blacklick Woods, a park in the Metropolitan Park District of Columbus, Ohio. The entrance to Blacklick Woods is ¾ mile east of the intersection of Livingston Avenue and Brice Road in the middle eastern section of Franklin County. Eleven acres of the center section of the park were surveyed and mapped. The center section is about 16 acres in extent, and the entire tract is 60 acres. The site is on the late Wisconsin till plain and the topography is very gently rolling to flat. The vegetation here is Swamp Forest interspersed with Beech-Maple. The dominant trees are: American Elm, White Ash and Red Maple in the Swamp Forest community and American Beech and Sugar Maple in the Beech-Maple community (cf. Gilbert, 1953 and Fritts, 1953).

A few trees were cut off this tract before it was established as a park. Most of the timber cut was White Ash. The amount, however, was not great, and it was long enough ago that the canopy is not open over any stump. The general appearance is such that without the stumps as evidence it would be difficult to ascertain timbering disturbance. The canopy is open in several places in this forest tract but because of wind fall. These conditions will in no way affect the results of the study inasmuch as the plant communities are being used only as a sampling population.

Each tree four inches or over in diameter breast height was included and a record kept of identification. The constructed map was used in all sampling operations. From the field record the true values were calculated for all the trees in the stand as one group, and for American Beech, Sugar Maple, American Elm, White Ash, and Red Maple individually. All other species were considered as another single group. The total number of trees and the total number in each of the categories were counted, and these totals were divided by 11 to give the number of stems per acre. A similar procedure yielded the values for basal area per acre.

Following is a list of the species which comprise the tree vegetation of this site:

		No. in area 4" or more in diam.
Dominants		
American Beech	*Fagus grandifolia Ehrh.**	411
Sugar Maple	*Acer sacharum L.*	92
American Elm	*Ulmus americana L.*	440
Red Maple	*Acer rubrum L.*	28
White Ash	*Fraxinus americana L.*	210
		1181
Associates		
White Oak	*Quercus alba L.*	4
Swamp White Oak	*Qpercus bicolor Willd.*	2
Burr Oak	*Quercus macrocarpa Michx.*	1
Pin Oak	*Quercus palustris Muenchh.*	2
Red Oak	*Quercus rubra L.*	3
Black Walnut	*Juglans nigra L.*	6
Black Cherry	*Prunus serotina Ehrl.*	16
Shagbark Hickory	*Carya ovata K. Koch.*	34
Bitternut Hickory	*Carya cordiformis K. Koch.*	19
Honey Locust	*Gleditsia triacanthos L.*	1
Red Elm	*Ulmus rubra Muhl.*	**
Swamp Rose	*Rosa carolina L.*	
Spring Beauty	*Claytonia virginica L.*	
Cutleaf Toothwort	*Dentaria laciniata Muhl.*	
Swamp Buttercup	*Ranunculus septentrionalis Poir.*	
Smooth Yellow Violet	*Viola pensylvanica Michx.*	
Jacob's Ladder	*Polemonium reptans L.*	
Dutchmen's Breeches	*Dicentia Cucullaria Bernh.*	
Kidneyleaf Crowfoot	*Ranunculus abortivus L.*	
Wild Carrot	*Daucus Carota L.*	
False Mermaid	*Floerkea proserpinacoides Willd.*	

* Nomenclature after Fernald (1950).
** Combined with American Elm.

Fig. 1 is a photograph of the winter aspect at Blacklick Woods. American Beech is prominent in the foreground, American Elm is in the background.

Fig. 2 is a photograph of the summer aspect at Blacklick Woods. Again American Beech and American Elm are prominent. The path in Fig. 2 is the boundary of the study area. The portion of the forest on the left hand side of the picture is included in the study area.

Fig. 1. Blacklick Woods, winter aspect.

Hackberry	*Celtis occidentalis L.*	5
		93
Small Trees		
Flowering Dogwood	*Cornus florida L.*	8
Blue Beech	*Carpinus caroliniana Walt.*	69
Ironwood	*Ostrya virginiana K. Koch.*	6
		83
	Total:	1357

Other shrubs and herbs at Blacklick are included in the following list:

Shrubs	
Moonseed Vine	*Monispormum canadense L.*
Creeping Wahoo	*Euonymus obovatus Nutt.*
Poison Ivy	*Rhus radicans L.*
Spice Bush	*Lindera Benzoin Blume*
Elderberry	*Sambucus canadensis L.*
Gooseberry	*Ribes cynosbati L.*
Herbs	
Sensitive Fern	*Onoclea sensibilis L.*
Jewelweed	*Impatiens spp.*
Purple Violet	*Viola papilionacea Pursh*
Solomon's Seal	*Maianthemum canadense Desf.*
Bulbous Bittercress	*Cardamine bulbosa BSP.*
Great White Trillium	*Trillium grandiflorium Salisb.*
Sessile Trillium	*Trillium sessile L.*
Nodding Trillium	*Trillium cernuum L.*
Purple Phlox	*Phlox divaricata L.*
Jack-in-the-Pulpit	*Arisaema triphyllum Shott*

Fig. 2. Blacklick Woods, summer aspect.

Sampling Methods:

Variable Radius Plotless Method

With the Variable Radius Plotless method (Bitterlich, 1948) a tally is made of all trees that are at a distance of no greater than 33 times their diameter from a given sampling point. This is accomplished by counting only those trees whose trunks subtend an arc greater than 104.18 minutes when viewed from the sampling point. This is ascertained by an angle gauge. The number of trees tallied multiplied by ten yields an estimate of basal area per acre in square feet. Tallies are made from several points and the numbers of counts reduced to averages before multiplying by ten. Ten is, in this case, the basal area factor and is specifically associated with the angle 104.18 minutes. (For other angles and Basal Area Factors, see Grosenbaugh, 1952). This same procedure may be used to estimate the basal area per acre of a species, size class, or combination of species and subclasses.

If basal area per acre of a size class is calculated, the number of trees per acre in that size class can be estimated by dividing the basal area per acre of the size by the area of a nominal tree at the midpoint of that size class.

It was not practical to sample the map with an angle gauge. Because of the scale of the map, the trunk diameters if drawn, would be too small to tally accurately. Instead the distances at which all trunk diameters (from 4.0″ to 36.0″ by 1/10″ increments) would subtend an angle of 104.18 minutes where calculated. Only those trees were counted that were closer to the sampling point than necessary for their trunks to subtend an arc of 104.18 minutes. Twenty-five points were selected at random on the map and the sampling conducted in the manner described. The estimates are tabulated in Tables 1 and 2.

Random Pairs Method

The procedure outlined by Cottam and Curtis (1949) was followed in the random pairs sampling. Compass direction and distances between points were decided beforehand to assure adequate coverage.

The direction lines were selected to cross the area diagonally and the distance between points was set at 20 yards.

From each point a line which included the point and the nearest tree was used as the bisector for the recommended 160° angle of exclusion. The distance to the tree closest to the tree on the bisector but outside the 160° angle was measured, and the size and identification of both trees was noted. This constituted one sample by random pair sampling. This procedure was duplicated at each point spaced 20 yards apart on the direction lines. The recommended 40 samples were taken. Number of trees per acre was estimated assuming a hexagonal uniform distribution of trees in space. Basal area per acre was estimated by using average diameter. These estimates are tabulated in Tables 1 and 2.

Quadrat Sampling

Two sizes of quadrats were used to sample the map population, one 4 yards square and the other 10 yards square (Cain, 1934). Twenty-five locations for each quadrat size were determined at random. The estimates of basal area per acre and number of trees per acre are indicated in Tables 1 and 2.

Transect Sampling

Bauer (1943) recommended the use of transects for sampling situations where the individuals of the community are of various sizes. His recommendation was the result of sampling experiments using both quadrats and transects. Buell and Cantlon (1950) working in the New Jersey Pine Barrens also compared the transect to the quadrat and concluded it was more efficient for estimating stand composition and basal area per acre. Bormann (1953) investigating the statistical efficiency of sample plot size and shape concluded that for the area he sampled transects either 4×140 meters or 10×140 meters that crossed noticeable vegetation or soil bands gave the best estimate of total true vegetation in terms of basal area. He sampled an area 140×140 meters which he completely enumerated and mapped.

Four transects were used to estimate stems per acre and basal area per acre. Two crossed the width of the area (No. 1 and 2) and two crossed the length of the area (No. 3 and 4). There is a slight banding of the vegetation pattern across the width of the area. The two transects that cross the width of the area tend to be parallel to the banding, and the two that cross the length cross the banding. The transect sizes are as follows: (1) 4×95.8 yards, (2) 8×120.8 yards, (3) 4×278.7 yards, and (4) 8×304.1 yards. The estimates for basal area per acre and stems per acre are in Tables 1 and 2.

Table 1 consists of the true values for basal area per acre in square feet and the estimates of these derived from the various sampling techniques. Values are included for total basal area per acre as well as for American Beech, Sugar Maple, American Elm, White Ash and Red Maple. All others are placed in a single category. Any row of the table contains the true value for a single category and all the estimates of this true value. Any column but the first of the table contains all the estimates of one sampling method. The first column contains the true values for all categories.

Table 2 is set up the same way except that it contains values for number of stems per acre.

In each case where random samples were taken, it was done in the following manner. Since the map was drawn on graph paper (10 lines per inch) the blocks across the horizontal and vertical extent of the map were numbered. This resulted in a coordinate system, where any block on the map could be designated by a number along the horizontal extent and a number along the vertical extent. By means of a table of random numbers, pairs of coordinates were chosen, and the blocks they represented, as random locations.

TABLE 1. Basal area per acre in square feet: estimates and true values.

Species	True value	Plotless	Random pairs	4 yard quadrat	10 yard quadrat	Transects 1	2	3	4
Total	126.6	122	108.2	422.9	148.3	276.3	176.4	120.5	119.1
American Beech	62.9	38.4	37.8	182.2	43.3	45.8	20.4	27.5	82.0
Sugar Maple	6.2	7.2	5.4	19.9	10.9	—	21.0	13.7	9.3
American Elm	33.6	43.6	32.5	80.7	46.1	161.1	89.6	20.6	30.3
White Ash	12.0	20.0	16.2	70.7	30.6	45.8	21.0	30.9	9.2
Red Maple	2.6	4.0	2.7	19.9	10.9	—	9.0	6.7	3.6
Others	9.4	8.8	13.5	60.3	6.5	23.0	3.0	24.1	18.3

TABLE 2. Stems per acre: estimates and true values

Species	True value	Plotless	Random pairs	4 yard quadrat	10 yard quadrat	Transects 1	2	3	4
Total	123.4	194.6	125.0	479.5	205.6	145.4	283.8	145.6	124.2
American Beach	37.4	38.5	43.7	201.4	60.0	24.1	52.8	33.2	49.7
Sugar Maple	8.4	15.4	6.2	22.1	15.1	—	33.8	16.6	9.6
American Elm	40.0	72.3	37.5	89.2	63.9	84.8	144.2	24.9	32.4
White Ash	19.0	36.8	18.7	78.1	42.5	24.1	33.8	37.4	9.6
Red Maple	2.6	6.6	3.1	22.1	15.1	—	14.5	8.2	3.8
Others	16.0	25.0	15.6	66.6	9.0	12.1	4.8	29.1	19.1

Analysis of the Data: To provide a quick and simple assessment of the sampling methods, percentage errors were calculated for each estimate of each sampling method compared to the corresponding true value. The percentage error values were calculated by dividing

TABLE 3. Percentage errors of sampling estimates and true values, basal area per acre

Species	Plotless	Random pairs	4 yard quadrat	10 yard quadrat	Transects			
					1	2	3	4
Total	− 3.6	− 0.6	+242.7	+ 17.1	+118.2	+ 39.3	− 4.8	− 5.9
American Beech	−38.9	−39.9	+189.6	− 31.2	− 27.2	− 67.5	− 56.3	+30.3
Sugar Maple	+ 1.6	− 1.3	+220.9	+ 75.8	−100.0	+238.7	+122.9	+50.0
American Elm	+29.7	− 3.3	+140.2	+ 37.2	+379.4	+166.6	− 38.7	− 9.8
White Ash	+66.6	+35.0	+489.1	+155.0	+281.6	+ 75.0	+157.5	−23.3
Red Maple	+53.8	+38.4	+665.3	+319.2	−100.0	+246.1	+157.7	+38.4
Others	− 0.6	+43.6	+547.3	− 30.8	+144.6	+ 68.1	+156.3	+94.6

TABLE 4. Percentage errors of sampling estimates and true values for number of stems per acre

Species	Plotless	Random pairs	4 yard quadrat	10 yard quadrat	Transects			
					1	2	3	4
Total	+ 57.7	+ 1.3	+288.6	+ 66.6	+ 17.8	+129.9	+ 17.9	− 0.65
American Beech	+ 2.9	+16.8	+438.5	+ 60.4	− 35.6	+ 41.2	− 11.2	+32.8
Sugar Maple	+ 83.3	−26.1	+163.0	+ 79.7	−100.0	+302.3	+ 97.6	+14.2
American Elm	+ 80.7	− 6.2	+123.0	+ 59.7	+112.0	+260.5	− 37.7	−19.0
White Ash	+ 93.6	− 1.6	+311.0	+123.6	+ 26.8	+ 77.8	+ 96.8	−49.4
Red Maple	+153.8	+19.2	+750.0	+480.7	−100.0	+457.6	+215.4	+46.1
Others	+ 56.2	− 2.6	+316.2	− 37.5	− 24.4	− 70.0	+ 81.8	+19.4

the difference between an individual sampling estimate and the true value by the true value and converting to a percentage.

$$\frac{\text{True value} - \text{sampling estimate}}{\text{True value}} \times 100 = \text{Percentage Error}$$

In the ideal case, the percentage errors would be zero. It follows then that those estimates which yield the smallest percentage errors would be the best estimates. The signs were retained to show the direction of error. The percentage error values for basal area per acre are shown in Table 3, and for stems per acre in Table 4.

Considering the sampling methods as a whole, the percentage errors for Random Pairs were lowest for both basal area per acre and stems per acre. The 4-yard quadrat is the poorest sampling method by this criterion. The percentage errors for the 4-yard quadrat are above 100% in every case. The direction of error for each estimate for the 4-yard quadrat was positive, indicating that this sampling method overestimated the value in every case.

An analysis for paired comparisons was made of the array of true values with the individual arrays of sampling estimates. This was done to assess the estimates of the individual methods as a whole. In order to perform the analysis for paired comparisons, it was necessary to transform the data: – in each individual case the values derived from a sampling method were added to the true values and then each of them calculated as a percentage of the total of the two values. As an example, the data for stems per acre for the plotless variable radius method and true values are arrayed in Table 5 together with the transformed data. This transformation gives the effect of replications and the t-test can be applied.

TABLE 5. Example of transformation of data. Stems per acre, Plotless and True Value

Species	True Value	Plotless	Sum of 1 and 2	Per cent True	Per cent Plotless
Total	123.4	194.6	318.0	38.8	61.2
American Beech	37.4	35.8	75.9	49.3	50.7
Sugar Maple	8.4	15.4	23.8	35.3	64.7
American Elm	40.0	72.3	112.3	35.6	64.4
White Ash	19.0	36.8	55.8	34.0	66.0
Red Maple	2.6	6.6	9.2	28.3	71.7
Others	16.0	25.0	41.0	39.0	61.0

The statistical hypothesis tested is that the differences between the means for true values and sample values is not different from zero. If the calculated t values are less than t at the 5% level of significance, the hypothesis is accepted and the differences are attributed to chance. If the calculated t values are greater than t at the 5% level, the hypothesis is rejected. The differences then are presumed to be greater than would occur by chance alone.

Pairing each sampling method with the true values yielded the t values indicated in Table 6. t at the 5% and 1% level is also indicated in the table.

TABLE 6. Calculated t values

Plotless	Random pairs	4 yard quadrat	10 yard quadrat	Transects 1	2	3	4
(a) Basal area per acre							
3.624	1.357	12.14	3.6711	5.420	7.596	5.758	4.935
(b) Stems per acre							
5.278	0.881	11.31	5.281	3.710	6.954	4.366	3.325

t .05 = 2.447 df = 6
t .01 = 3.707

t values for random pairs were the only ones that were less than t at the 5% level. The statistical hypothesis of differences between the true and estimated values for random pairs being not different from zero is accepted. That is, the difference between the random pairs estimates and the true values is attributed to chance. The differences are what might normally be expected in drawing samples from such a population. All other sampling methods yielded t values that were greater than t at the 5% level. The differences in these cases can not be attributed to chance alone. That is, they are greater than those normally expected from sampling such a population. This statement is paradoxical in view of the fact that all sampling was done with the same population, and the differences must be considered normal, in the absolute sense, to sampling this population. The differences must be assigned then, to the bias of the individual sampling methods.

The value of t at the 1% level is included for those who might question its absence.

To assess each item of each sampling method, a t-test for the difference between an observed and expected proportion was performed on the transformed data. Each item of the sampling methods was compared to the appropriate true value. The expected proportion was 50% true value and 50% sample value. This follows from the transformation where each item of the sampling methods was combined individually with its corresponding true value and both calculated as percentages of the total. After such a combination and percentage calculation the expectation is equal percentages of true value and sample value and the deviation of the percentages from the expected 50:50 can be analyzed. This was done and the results of the analysis are in Tables 7 and 8. t at the 5% and 1% levels of significance are indicated in the tables.

The hypothesis of differences between percentage values not being different from zero is accepted if calculated t is smaller in numerical value than t at the 5% level of significance. That is, if calculated t is smaller than t at the 5% level it is assumed that the differences between percentage values is due to chance alone.

TABLE 7. Calculated values for t for the test between an observed and expected proportion: basal area per acre

Species	Plotless	Random pairs	4 yard quadrat	10 yard quadrat	Transects 1	2	3	4
Total	.180	.780	5.480	.780	3.780	1.640	2.240	3.260
American Beech	2.420	2.480	4.880	.820	3.560	5.100	3.920	3.360
Sugar Maple	.740	.680	4.760	2.740	10.000	5.440	3.720	2.000
American Elm	1.300	.160	4.140	1.580	6.560	4.700	2.380	.500
White Ash	2.500	1.360	7.100	4.380	5.860	2.720	4.360	1.320
Red Maple	2.140	.200	7.780	6.180	10.000	5.520	4.440	1.620
Others	2.320	1.800	7.320	1.820	4.200	5.160	4.400	3.220

t .05 = 1.95996
df = 0
t .01 = 2.57582

TABLE 8. Calculated values of t for the test between an observed and expected proportion: stems per acre

Species	Plotless	Random pairs	4 yard quadrat	10 yard quadrat	Transects 1	2	3	4
Total	2.240	.060	5.900	2.500	.820	3.940	.820	.040
American Beech	.140	.780	6.860	2.320	2.160	1.700	.580	1.420
Sugar Maple	2.940	1.500	4.500	2.860	10.000	6.780	3.280	.660
American Elm	2.880	.320	3.820	2.300	3.580	5.660	2.320	1.040
White Ash	3.200	.080	6.080	3.840	1.180	3.440	3.280	3.280
Red Maple	4.340	.880	7.900	7.060	10.000	6.960	5.180	3.880
Others	2.200	.120	6.120	2.800	1.380	5.380	2.900	.880

t .05 = 1.95996
df = 0
t .01 = 2.57582

In the comparisons for basal area per acre, random pairs yielded only one t value greater than t at the 5% level of significance. That value is for American Beech. All other estimates for random pairs are acceptable. Next in order of efficiency is the 10 yard quadrat with four acceptable estimates for total, American Beech, American Elm, and others. Transect 4 had acceptable estimates for White Ash and Red Maple. The plotless variable radius method yielded acceptable estimates for total, Sugar Maple and American Elm. Transect 2 had only one acceptable estimate, total; and the 4 yard quadrat and transect 3 had no acceptable estimates.

For stems per acre, all random pairs estimates were acceptable. Transect 4 had five acceptable estimates, total, American Beech, Sugar Maple, American Elm, and others. Transect 1 had three acceptable estimates, total, White Ash, and others. Transect 2 and the plotless variable radius method had only one acceptable estimate, American Beech. The 4 yard quadrat and 10 yard quadrat had no acceptable estimates.

Conclusions: The most efficient sampling method for this area for estimates of both basal area per acre and stems per acre is the random pairs method.

No sampling method gave an estimate for American Beech for basal area per acre that could be accepted at the 5% level of significance (cf. Table 7).

The failure of all methods to provide accurate estimates of the basal area per acre of beech is probably associated with the fact that there are more large beech per given number of trees than any other species for the same given number.

Bormann's (1953) recommendation that sampling units should cross vegetation and soil boundaries is upheld by the results of this study, at least for Transect 4. The two transects that did not cross these boundaries yielded poorer estimates of basal area per acre and stems per acre than Transect 4 which crossed the vegetation and soil boundaries.

For the 4 yard quadrat sampling method to have yielded good estimates of the true values, many of them would have to have contained no trees. An average of only one tree per quadrat would have yielded an estimate of 225 trees per acre.

Shanks (1954) compared some of these sampling methods in Appalachian Forest types (spruce-fir and cove hardwoods). His findings indicated that the plotless variable radius method gave the best estimates in that situation, while the random pairs method gave a large small-sample bias. This leads to the inference that sampling methods devised in one particular type of forest community may not yield valid information in another, especially if the sampling technique is empirically tested and altered to suit one particular type of forest community structure.

The quadrat and transect methods of sampling may not yield good estimates of forest community characteristics because the trees are secondary to the unit area of the sampling method. That is, area is the unit sample and the trees per sample unit area may vary widely. This may not take into account the peculiarities of the distribution of the tree population in space and therefore lead to biased results. This factor may explain why Bourdeau failed to get appreciably different results with stratified random and selective quadrat sampling.

It must be thoroughly understood that these results apply particularly to the study area and generally to similar deciduous forest communities disposed over similar terrain.

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