AN EVALUATION OF THE VARIABLE-RADIUS AND PAIRED-TREE METHODS IN THE BLACKJACK-POST OAK FOREST[1]

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Introduction

A long-term investigation on the deciduous forest frontier was inaugurated at the University of Oklahoma in 1953. Among other procedures, this program envisaged the analysis of 200 to 300 forest stands along the forest-prairie ecotone. Reconnaissance was completed in the south-central and southeastern sections of the state in the summer of 1953. During this period, 85 stands were located and described in a qualitative manner. In view of the considerable number of stands to be analyzed, it was imperative that a relatively fast method of analysis be utilized. The purpose of this paper is to compare the results derived by the variable-radius and paired-tree methods with the data obtained from the census of a blackjack-post oak forest. The writers are indebted to Prof. Joe Anderson for help in the field work and to Dr. and Mrs. John R. Whitaker for editorial assistance.

Location and Description of Stand

The stand upon which the census was executed is located 15 miles east and one mile south of Norman, Oklahoma. It is in the southwest quarter of section 25, T9N, R1E, Cleveland County. The 160 acre tract is on gently rolling topography, with a ravine traversing the western portion in a north-south direction. According to reliable information, the tract had never been cut over, had been grazed only lightly, but had been burned-over periodically. The stand is fairly dense with considerable woody undergrowth on the slopes and in the flats along the ravine, but is rather open with a good grass cover in the higher and drier portions of the tract.

The dominants, as indicated both in the reconnaissance and in the census, are blackjack (oak), *Quercus marilandica* Muenchh., and post oak, *Quercus stellata* Wang. Common secondary species are (black) hickory, *Carya texana* Buckl., and black oak, *Quercus velutina* Lam. Twenty-three other woody plants, as well as numerous grasses and forbs, were encountered in the stand but are omitted from consideration in this discussion. Except for the summary, only common names will be used in the present paper.

[1] Contribution of the Oklahoma Biological Survey, Dr. Carl D. Riggs, Director.

Results of Census

In preparation for the census of the blackjack-post oak stand, two rectangular plots of slightly different composition were delineated by painting rings on the boundary trees. These units, designated as south and north plots, possessed areas of 4.36 and 4.63 acres, respectively. In sampling, all woody plants with a DBH of three inches or more were measured and entered on a form. From these data, the following compilations were made for each tree species in the south plot, in the north plot, and in the entire stand: number of trees, trees per acre, relative density, total basal area, and basal area per species.

It will be observed that the composition of the south and north plots varied somewhat although the order of abundance was similar (Table I). In the south plot, there were considerably more blackjacks than in the north plot, whereas there were fewer post oaks, hickories, and black oaks. The number of trees per acre was greater in the south plot.

Compared with most deciduous forests, the total basal area is very low (52.3 square feet) in the blackjack-post oak stand. Of the basal area for the entire stand, blackjack and post oak contributed over 86 per cent. Although blackjack trees outnumbered post oak trees by more than two to one, the basal areas of these species were similar in both plots (Table I). This is correlated with the fact that only one per cent of the blackjacks, as against 28 per cent of the post oaks, possessed a DBH of 12 inches or over. Compared with the post oak, the blackjack had the higher basal area in the south plot but a lower value in the north plot. This reversal is due primarily to the lower number of blackjack trees in the north plot (Table I).

Description of Variable-Radius and Paired-Tree Methods

The variable-radius method of forest sampling was developed in Germany by Bitterlich and introduced into the United States by Grosenbaugh (1952a, 1952b). More recently this method has been compared with the paired-tree technique of Cottam and Curtis (1949) in Appalachian forest types by Shanks (1954). The variable-radius method is based on the principle of point sam-

TABLE I. *Number of trees and basal area in the blackjack-post oak forest according to the complete census*

Species	South Plot			North Plot			Entire Stand		
	Trees	No./acre*	Basal Area Sq. ft./acre	Trees	No./acre*	Basal Area Sq. ft./acre	Trees	No./acre	Basal Area Sq. ft./acre
Blackjack........	593	136.0	25.3	395	85.3	21.3	988	109.9	23.3
Post oak.........	204	46.8	20.3	231	49.9	23.6	435	48.4	22.0
Hickory..........	83	19.0	4.2	125	27.0	7.1	208	23.1	5.6
Black oak........	21	4.8	0.9	37	8.0	2.0	58	6.4	1.4
Totals........	901	206.6	50.7	788	170.2	54.0	1689	187.8	52.3

*South plot, 4.36; North plot, 4.63 acres.

pling. A hand-held angle-gauge is used to determine those trees which are within a distance from the sampling point no greater than 33 times their diameter. The angle-gauge is made by mounting a crossarm, one inch wide, at one end of a 33-inch stick and a similar piece of metal or wood, with a peephole near its center, at the other end. With this angle-gauge, the angle has been so selected that the tally at a given point need only be multiplied by a factor of 10 to yield basal area in square feet per acre. Thus, a tally of 7 trees at a point would indicate a basal area of 70 square feet per acre and if this tally were composed of 4 blackjacks and 3 post oaks, then basal areas per acre of 40 square feet and 30 square feet respectively would be indicated.

The paired-tree method also is based on the principle of point sampling. At a given point, the pair of trees is selected as follows: "the first is the tree nearest the sample point, the second is the tree nearest to the first outside the 160° sector bisected by a line from the sample point to the first tree. Diameters of the sample trees and distances between them provide the basis for computing stand composition" (Shanks 1954). The standard practice in Wisconsin has been to use trees 4 inches or more in diameter and to use 40 points, or 80 trees, per stand. In the present study, a lower limit of 3 in. DBH was selected because of the small size of all trees in the blackjack-post oak forest. Forty points were utilized in both the variable-radius and paired-tree techniques.

Choice of a Method

In deciding on a method for analyzing the 200 to 300 forest stands along the deciduous forest frontier, three considerations were paramount: 1. the method must be rapid, 2. it should require little equipment, and 3. it must include data for frequency, density, and basal area compilations. Both the variable-radius and paired-tree methods met the first two requirements readily. Regarding the third item above, Shanks (1954) stated that, "variable-radius plotless sampling is an efficient means of assembling forest stand data, in terms of square feet basal area per acre and percentage composition and their variability. . . . Frequency data are directly available, but they differ from the usual frequency data. . . . they express the frequency of effective vegetational contribution rather than frequency of botanical presence." Curtis and Cottam (1949) declared that the random pairs method, "proved to be a very rapid and reasonably accurate means of obtaining the frequency, density and dominance [basal area] of the tree species of oak opening, oak-hickory, and maple-basswood forests." Unfortunately, the variable-radius method proved unsuitable for determining frequency and density and the paired-tree method did not provide sufficiently accurate data on frequency, density, or basal area. We have resorted, therefore, to a combination of the variable-radius method for basal area data, and arm-length transects between sampling points for data on frequency and density.

Defects of the Variable-Radius Method

The variable-radius method has been used by Shanks (1954) for determining frequency. It has been used also for the construction of phytographs which include density and frequency data (Shanks 1954). In the study of the blackjack-post oak forest, the data on relative frequency by variable-radius sampling did not agree closely with those derived from transects. According to the variable-radius technique, the frequency was too low for blackjack and too high for post oak (Table II). Since the blackjacks were somewhat smaller than the post oaks, it was thought that the larger trees might have been favored by the variable-radius method.

To test this theory, a theoretical population was fashioned as follows: a grid of heavy lines one inch apart was constructed and another series of light lines one-third of an inch apart was placed between the original lines, thus giving a grid of one-third inch squares. Then symbols represent-

Table II. *A comparison of data in the blackjack-post oak forest obtained by the complete census, arm-transect, paired-tree, and variable-radius methods*

Species	Number per Acre			Relative Density			Relative Frequency		
	Census	Transect	P−T	Census	Transect	P−T	Transect	P−T	V−R
Blackjack........	109.9	130	68.7	58.5	60.5	44.9	53.8	42.7	38.8
Post oak.........	48.4	45	38.6	25.8	20.9	25.2	23.1	25.0	34.7
Hickory.........	23.1	25	40.2	12.3	11.6	26.2	15.4	27.9	19.4
Black oak........	6.4	15	5.7	3.4	7.0	3.7	7.7	4.4	7.1
Totals........	187.8	215	153.2	100	100	100	100	100	100

ing large trees were placed at the intersections of the heavy lines and other symbols depicting small trees were established at the junctions of the light lines. This provided a theoretical, hypodispersed population of trees, with small trees eight times as numerous as the large trees. Since the small trees were assigned a diameter one-third that of the large trees, the small trees on the grid would be sampled at a maximum distance of one-third that of the large trees by the variable-radius method. It was a simple matter to establish sampling points and to tally the population with the aid of a strip of cardboard with cross-marks one-third of an inch and one inch from the end held at the sampling point by a pin. With a sample of 30 points, the frequency percentage for both small and large trees was 100. The maximum plot radii for sampling the theoretical population by the variable-radius technique were changed, therefore, to 1/12 inch and 1/4 inch for the small and large trees respectively. When the population was sampled under the above conditions, trees of each diameter were recorded at 9 out of a total of 30 sampling points, giving a frequency percentage of 30 for each tree size. Since the small trees were eight times as numerous as the large trees a much higher frequency percentage (80-100) for the small trees might have been expected. This exercise demonstrates that meaningful frequency values cannot be determined by the variable-radius method in a population with different tree diameters. Apparently Shanks (1954) also realized that frequency was affected by tree size since he stated that, "only those minor species which are consistently of small size tend to have values lower than their conventional plot frequency values in the stand, such as serviceberry, mountain holly, and mountain ash in Table I."

Densities can be computed from basal area data obtained by the variable-radius method if size distributions are known. This, of course, necessitates estimating or measuring the diameter of each tree and tallying it in its appropriate diameter class (Shanks 1954, Grosenbaugh 1952a). This procedure demands more time in the field and also requires considerable extra time for calculations. Moreover, the variable-radius method is not suitable for the determination of sapling density because of the relatively small diameter of saplings.

Defects of the Paired-Tree Technique

A comparison of the data on density derived from the paired-tree technique with those from the complete tree census is presented in Table II. On the basis of data procured by this technique, the number of blackjack trees was much too low, the count of hickory trees was too high, and the total tally of all trees was too low when compared to the numbers derived from the census (Table II). Furthermore, the order of abundance with reference to post oak and hickory was reversed by the paired-tree method. On the basis of relative density (percentage of total trees), the same relation obtains: blackjack too low and hickory much too high (Table II). Since no frequency data were taken in the census, the relative frequencies by the paired-tree method will be compared with those derived from 40 arm-length transects of 0.01 acre each. It will be observed that the relative frequencies, by the paired-tree technique, are too low for blackjack and too high for hickory (Table II), a relationship very similar to that obtained for density and relative density.

In the matter of basal area, the paired-tree technique was also quite inaccurate. Basal area of the blackjack, as well as the total basal area, was much too low. Furthermore, the order of blackjack and post oak, with reference to basal area, was reversed by the paired-tree method (Table III). It is possible that an improvement might be made in the paired-tree method if a new exclusion angle were determined, but this was not attempted.

An advantage of the paired-tree technique was the relatively small time of sampling (2.5 hours for 40 points). However, considerable time was required in making compilations. For the variable-radius method, approximately two hours were required for a 40-point sample. Since this method

TABLE III. *A comparison of basal area data in square feet per acre in the blackjack-post oak forest determined by the complete census, variable-radius (three samples), and paired-tree techniques*

	Census	Variable-radius			Paired-tree
		First	Second	Third	
Blackjack...	23.3	28.0	24.5	24.0	16.4
Post oak....	22.0	20.8	22.2	19.5	19.9
Hickory....	5.6	7.2	4.0	3.8	4.6
Black oak...	1.4	2.0	2.8	1.8	1.6
Totals......	52.3	58.0	53.5	49.1	42.5
Percentage Deviations..	Base	+10.9	+ 2.3	− 6.1	−18.7

was not deemed desirable for obtaining density and frequency data in the blackjack-post oak forest an additional hour was required for 40 arm-length transects of 0.01 acre each. It is probable, therefore, that there is little time differential between the paired-tree technique and the augmented variable-radius method. The latter method, however, was selected because of its greater accuracy.

The Augmented Variable-Radius Method

In the first sample by the variable-radius method, the basal area for the blackjack oak and the total basal area were somewhat higher than comparable data derived from the complete tree census (Table III). It was decided that this discrepancy might be due to the fact that the angle-gauge had not been calibrated. The angle-gauge must be fitted to each investigator, depending on the depth of the eyes and whether the worker wears glasses. This calibration was made according to the instructions given by Grosenbaugh (1952b): "The cross-piece, when viewed through the peep-hole, should exactly cover a 3-foot horizontal intercept at a distance of 99 feet from the eye. The distance between the cross-piece and peep-hole should be adjusted till this occurs." Using the calibrated angle-gauge, the basal area data were very similar to those procured by the census (Table III, second and third samples). Whereas the percentage deviation from the total basal area was + 10.9 in the first sample, those of the second and third samples were + 2.3 and − 6.1 respectively. In view of the fact that a deviation of ± 10 per cent is to be expected in any method of forest analysis, these data are excellent indeed.

Mean basal areas (sq. ft./acre) in the first sample by the variable-radius technique, with accompanying standard errors, were as follows: blackjack, 28.0 ± 2.5; post oak, 20.8 ± 2.5; hickory, 7.2 ± 1.6; black oak, 2.0 ± 0.7; and total, 58.0 ± 3.3. In the case of the dominants, blackjack and post oak, the standard errors approximated 10 per cent of the means. For the total basal area the standard error was much less (5.5%) than 10 per cent of the mean. Although the above data are not as reliable as those procured by Shanks (1954), it is believed that the sample utilized (40 points) is adequate for the determination of basal area in the blackjack-post oak forest.

In connection with the reliability of data on relative density, Cottam, Curtis and Hale (1953) state that, "Reasonable accuracy was attained when the number of individuals of the species in question exceeded 30 in the total sample." It will be observed that average tallies of 102 and 83 trees, respectively, were recorded for the dominant trees by the variable-radius technique (Table IV). These tallies are about three times the 30-tree figure suggested in the above statement. Significant also is the fact that the average total sample (216) was more than the number of trees per acre (188) according to the complete tree census. These findings also lend support to the belief that the sample of 40 points, by the variable-radius method, is adequate for forest analysis along the forest-prairie ecotone.

Since the variable-radius method proved undesirable for determining density or frequency, recourse was had to a series of paced, arm-length transects of 0.01 acre each between the 40 sampling points. It should be pointed out that the length of one's pace varies with such items as slope and obstructions, and that the total area covered would only approximate 0.40 acre. Although the absolute number of trees per acre might be changed, the relative number of trees (relative density) would not be affected. In the one sample presented, the number of trees per acre by the arm-transect method approached the census numbers fairly closely (Table II). Relative densities by this method also approximated the census figures. Since no frequency data were taken in the census, there are no frequencies with which the relative frequencies obtained by the arm-transect technique can be compared. How-

TABLE IV. *Number of trees, tallied in three samples by the variable-radius method*

	First	Second	Third	Average
Blackjack...	112	98	96	102
Post oak....	83	89	78	83
Hickory.....	29	16	25	23
Black oak...	8	10	7	8
Totals....	232	213	206	216

ever, it will be noted that the relative densities and relative frequencies obtained by the arm-transect technique are very similar (Table II).

Spatial Distribution of Individuals

Cottam, *et al.* (1953) stated that . . . "The student of plant communities is concerned with the distribution of objects in space. His first problem is the determination of the kinds of plants present and their relative numbers. Since it is usually impossible to examine all of the plants present, he confines himself to some kind of a sample of the vegetation . . . the results [of sampling] are affected in their accuracy by the actual dispersion of the plants on the ground. . . . Many of the methods now in use presuppose a random distribution of individuals in the population and are satisfactorily accurate when such conditions prevail." Goodall (1952) pointed out that if a species is randomly dispersed, density is the only additional information necessary to give a full description of its distribution. Based on samples from an artificial population, Curtis and McIntosh (1950) found that frequency values are too low for any given density if the species has a contagious distribution and too high if the species is hypodispersed. These same workers reported that density determinations are relatively similar for all three types of dispersion, but that there is some indication that highly contagious species are over-represented by relatively small quadrats.

The variable-radius sampling method furnishes data in such a form that the spatial distribution of the individuals of any given species can be rapidly calculated. Using data obtained by the variable-radius method, the distribution of the individuals of each of the four common trees of the blackjack-post oak forest was determined first by calculating the coefficient of dispersion, $K = \frac{V}{\bar{x}}$. In the above formula V equals the variance and $\bar{x}$ equals the mean number of individuals at each point. Using the limits for random distribution of K $= 1 \pm 2\sqrt{\frac{2n}{(n-1)^2}}$ (where n equals the number of sampling points), set by Blackman (1942), the individuals of all four species were indicated to have a random distribution (Table V).

The chi-square test for the fitted Poisson distribution was next applied to each species since the coefficient of dispersion, as pointed out by Blackman (1942), "is not a sensitive test for certain skew distributions." Again, a random distribution was indicated for all four species.

Since the chi-square test for the fitted Poisson distribution is a much more reliable indication of a random distribution, it is strongly recommended that such a procedure be followed. Poisson series based on means from 0.001 to 100 can be quickly set up by reference to Table I of Molina (1943). By use of that table, the above tests can be completed more rapidly than the coefficients of dispersion can be calculated. The test for blackjack is given as an example of the procedure in Table VI. It will be noted that the chi-square is quite small indicating a very close fit between the sample data and the appropriate Poisson series.

Table V. *Spatial distribution of tree species in the blackjack-post oak forest*

	K-value*
Blackjack	0.90
Post oak	1.22
Hickory	1.42
Black oak	1.08

*$K=\frac{V}{\bar{x}}$. Random distribution indicated if $K=1\pm0.46$ using limits set by Blackman (1942).

Table VI. *Comparison of distribution of individuals of blackjack with the appropriate Poisson series*

Number of individuals	Number points	Expected number for Poisson dist.	Deviation	Dev.² / Expected
0	2 } 8	2.4 } 9.2	1.2	0.16
1	6	6.8		
2	11	9.5	1.5	0.24
3	9	8.9	.1	0.001
4	6	6.2	.2	0.006
5	4 } 6	3.5 } 6.0	0	0.000
6	1	1.6		
7	1	0.7		
8	0	0.2		

$m=2.8$ $n=40$ Chi-square$=0.407$* Degrees of freedom$=3$

*A random distribution is indicated since the sample does not depart significantly from the Poisson series.

Summary

1. An evaluation of the variable-radius and paired-tree plotless sampling methods is presented herewith.
2. The standard for comparison was a complete tree census of a blackjack-post oak forest with blackjack, *Quercus marilandica* Muenchh., and post oak, *Quercus stellata* Wang., as the dominant trees, and hickory, *Carya texana* Buckl., and black oak, *Quercus velutina* Lam., as common secondary species.
3. In the stand investigated, the blackjacks were twice as abundant as the post oaks but had about the same total basal area.
4. The variable-radius method was found to be

unsuitable for obtaining data on frequency since large trees were favored by the sampling gauge. This method proved to be undesirable, also, for determining density for the following reasons: (1) extra time is required in the field to estimate the diameter class of each tree sampled, (2) considerable time is required for calculations and (3) the method is unsuitable for determining the density of saplings. The method proved very satisfactory for procuring data on basal area.

5. The paired-tree technique proved to be useful for procuring data on density, frequency, and basal area but was insufficiently accurate, due probably to the small sample utilized.
6. An augmented variable-radius method was chosen for future forest analysis. This consisted of the usual variable-radius technique for determining basal area, supplemented by 40 arm-length transects of 0.01 acre each for procuring data on density and frequency.
7. The variable-radius sampling method furnishes data in such a form that the spatial distribution of the individuals of any given species in a stand can be determined readily. Knowledge of the type of dispersion is important in interpreting any other kinds of information obtained about the stand. All four common tree species sampled by the variable-radius method in the blackjack-post oak forest were found to be randomly dispersed.

References

Blackman, G. E. 1942. Statistical and ecological studies in the distribution of species in plant communities. I. Dispersion as a factor in the study of changes in plant populations. Ann. Bot. **6**: 351-370.

Cottam, Grant, and J. T. Curtis. 1949. A method for making rapid surveys of woodlands by means of pairs of randomly selected trees. Ecology **30**: 101-104.

Cottam, Grant, J. T. Curtis, and B. W. Hale. 1953. Some sampling characteristics of a population of randomly dispersed individuals. Ecology **34**: 741-757.

Curtis, J. T., and R. P. McIntosh. 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology **31**: 434-455.

Goodall, D. W. 1952. Quantitative aspects of plant distribution. Biol. Rev. **27**: 194-245.

Grosenbaugh, L. R. 1952a. Plotless timber estimates new, fast, easy. Jour. Forestry **50**: 32-37.

———. 1952b. Shortcuts for cruisers and scalers. Sou. For. Exp. Sta. Occasional Paper **126**: 1-24.

Molina, E. C. 1943. Poisson's exponential binomial limit. D. Van Nostrand Co., New York.

Shanks, R. E. 1954. Plotless sampling trials in Appalachian forest types. Ecology **35**: 237-244.

ACTIVITY PATTERNS OF PERCH, *PERCA FLAVESCENS*, IN RONDEAU BAY OF LAKE ERIE[1]

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Introduction

The data for this investigation to determine the daily periods of the activity of perch were obtained by the use of gill-nets set in Rondeau Bay during the summers of 1951 and 1952. Rondeau Bay, with a maximum depth of 10 to 12 feet, is about five miles long and two miles wide (Fig. 1). It lies in Ontario on the north shore of Lake Erie, opposite Cleveland. It was connected to the lake only by a channel about 100 yards wide until the spring of 1952. At that time storms broke through the sand bar between the lake and the bay at site H. A second gap was formed just east of the former gap in the autumn of 1952.

Weekly net settings in 1951 revealed that different species of fish could be caught more readily at certain times of day than at others. In 1952, the investigation was directed towards the study of perch, *Perca flavescens* (Mitchill), because this species made up 90 per cent of the catch and showed a marked pattern of activity.

The capture of fish in gill-nets is an index of the activity of fish present in the area since the more active a fish the greater its chance of encountering the net and the less its chance of avoiding it. Also, the number of fish caught depends upon both the abundance of fish in the vicinity of the nets and the activity of the individual fish. Other factors, such as the amount of light, the turbidity and the manner in which the net is set, may influence the fish's chance of avoiding the net. If the fish move to another area for a portion of the day, then the net catches would reveal only the activity in a particular locality and would not give a true picture of activity. Thus, the rate at which non-migratory fish are caught re-

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