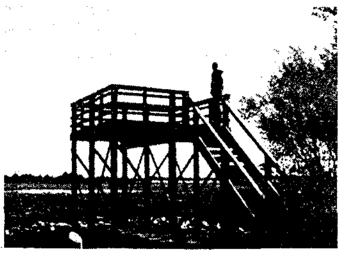

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TECHNICAL REPORT EL-88-23

DISTANCE SAMPLING TECHNIQUES

Section 6.2.2, US ARMY CORPS OF ENGINEERS WILDLIFE RESOURCES MANAGEMENT MANUAL

by

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Distance techniques represent a category of plotless vegetation sampling methods used to compare plant communities or assess changes in a community over time. They are best suited for sampling woody vegetation in moderate to dense stands. This report is designed to provide the field biologist with an overview of distance sampling methods and descriptions of specific techniques available for vegetation inventories on project lands.

General aspects of distance methods are discussed, and the point-centered quarter, T-square nearest-neighbor, and joint-point techniques are presented in detail. Criteria for the appropriate use and selection of each technique are given. Procedures for data collection and summarization of results are fully described, and examples are shown using data from field exercises. Personnel requirements and sampling limitations are discussed, and reproducible forms for recording field data are provided in the appendixes.

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PREFACE

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NOTE TO READER

This report is designated as Section 6.2.2 in Chapter 6 -- CENSUS AND SAMPLING TECHNIQUES, Part 6.2 -- VEGETATION SAMPLING TECHNIQUES, of the US ARMY CORPS OF ENGINEERS WILDLIFE RESOURCES MANAGEMENT MANUAL. Each section of the manual is published as a separate Technical Report but is designed for use as a unit of the manual. For best retrieval, this report should be filed according to section number within Chapter 6.

DISTANCE SAMPLING TECHNIQUES

Section 6.2.2, US ARMY CORPS OF ENGINEERS
WILDLIFE RESOURCES MANAGEMENT MANUAL

Distance sampling techniques provide information on plant community composition and structure without the large investment in time, equipment, and labor required for quadrat techniques. The data collected using distance techniques may be less detailed than those obtained using quadrats but are often sufficient for general characterizations, particularly of large areas. The variable-radius plot technique (Section 6.2.3) is similarly appropriate for survey studies but may not be as useful as distance techniques where vegetation is highly aggregated, understories are dense, or noncommercial species are of interest.

The rationale behind distance sampling techniques is that plant-to-plant or point-to-plant measurements are indicative of plant density. Furthermore, if the sampled plants are identified and some measure of dominance (e.g., basal area) is taken for each, distance techniques provide estimates of total and relative dominance and frequency, by species, for the sample area. These descriptive data are appropriate for most vegetation characterization studies, comparisons between areas, and comparisons over time. They may also provide much of the information needed for wildlife habitat quality evaluations and similar specialized studies.

This report presents an overview of 5 distance sampling techniques and further describes data collection and summarization procedures for three of these techniques, each of which may be appropriate for particular applications. Other distance techniques exist and may be preferable in some situations, or plot techniques may provide the required information more effectively or efficiently. Selection of a particular technique and sampling design, determination of sample adequacy, and analysis of summary data are discussed in Section 6.2.1, VEGETATION SAMPLING DESIGN AND DATA ANALYSIS.

OVERVIEW OF TECHNIQUES

Distance methods have a long history of use and refinement. Cottam and Curtis (1949) first described the random pairs method, and Skellam (1952) developed the nearest-neighbor method. To increase efficiency and the adequacy of data taken per point, Cottam et al. (1953) modified the random pairs method into the point-centered quarter (PCQ) technique. Batcheler (1971) modified the nearest-neighbor method to include 3, rather than 2, distance measurements from a sampling point. Variations of the distance methods have also been developed to increase their reliability in estimating the density of aggregated populations. Besag and Gleaves (1973) developed the T-square method (a modified nearest-neighbor method) for tests of randomness in a population, and Diggle (1975) modified the T-square method to estimate density of aggregated populations. Basic designs for distance techniques are described below and diagrammed in Figure 1.

Random pairs. This technique involves selecting the closest tree to a random sample point and establishing an imaginary line at a 90-deg angle to a line joining the point and its nearest neighbor (Fig. 1A). This line forms a 180-deg exclusion angle on the side of the line in which the nearest plant is located. The distance between the nearest plant and its nearest neighbor outside the exclusion angle is then measured.

Nearest-neighbor. This method is a simple procedure in which the closest tree to the sampling point is located and the distance from this tree to the nearest neighbor is measured (Fig. 1B).

Point-centered quarter (PCQ). The technique, a modification of random pairs, increases the amount of data gathered at each sampling point. From the sampling point, the distance to the closest tree in each quarter around the point is measured (Fig. 1C).

Joint-point. This is a modification of the nearest-neighbor method and requires the following measurements: (1) the distance from the point to the closest tree; (2) the distance from the closest tree to its nearest neighbor;

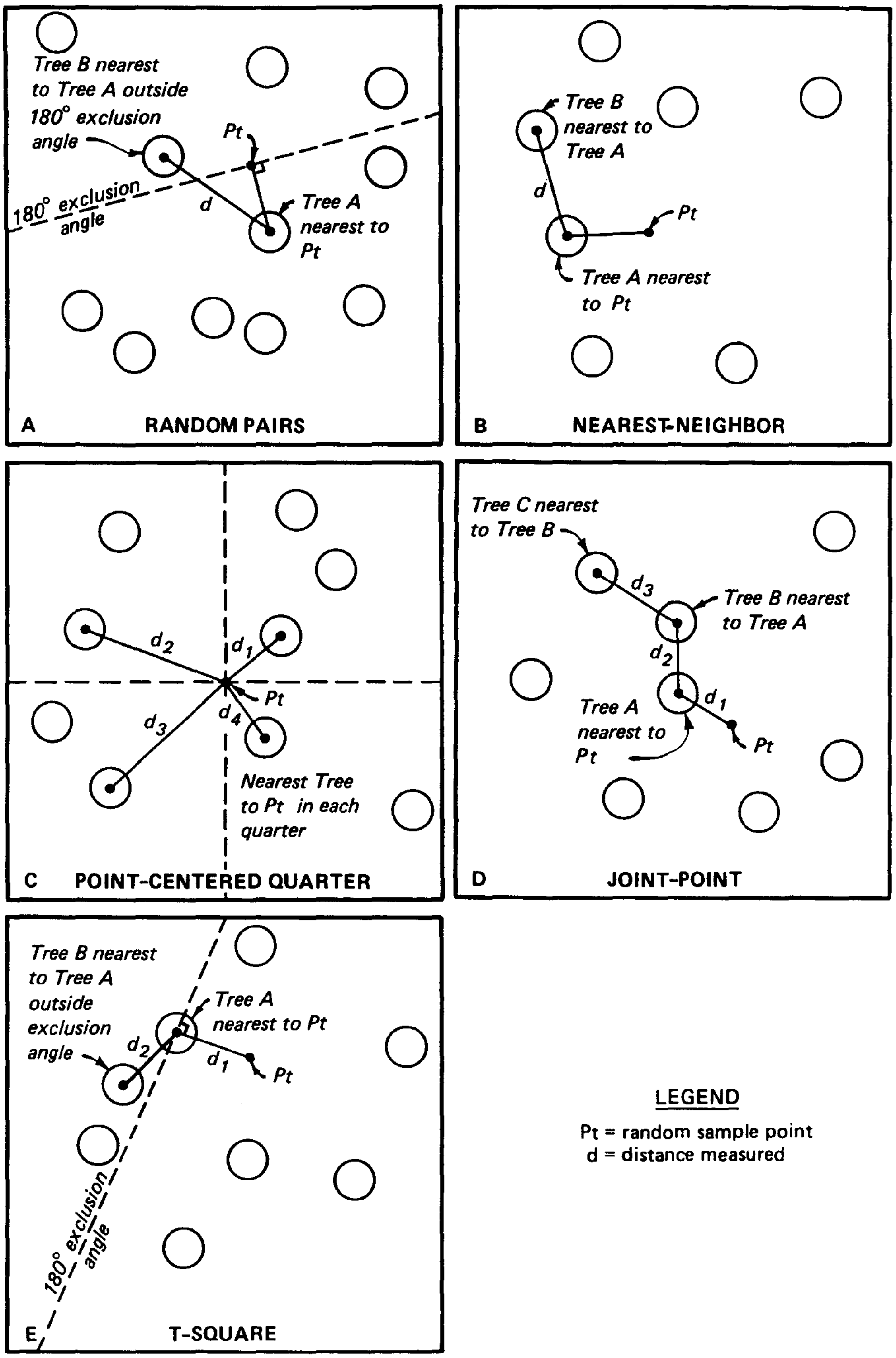


Figure 1. Comparison of distance sampling designs

and (3) the distance from the nearest neighbor to the next closest tree (Fig. 1D).

T-square nearest-neighbor (T-square). The distance from the random point to the closest tree is measured, and an imaginary line 90 deg to a line joining the point and the closest tree is constructed (Fig. 1E). This forms a 180-deg exclusion angle on the side of the line in which the random point is located. The distance from the closest tree to its nearest neighbor outside the exclusion angle is measured.

The PCQ method is a rapid technique, the T-square is generally regarded as an improvement on PCQ (Hays et al. 1981), and the joint-point is a special approach for aggregated plant populations (see Techniques Evaluation, page 23). Choosing the correct technique for a particular area and purpose is best accomplished by conducting a pilot study (see Section 6.2.1). The PCQ, T-square nearest-neighbor, and joint-point methods are discussed in detail below.

MATERIALS

Few materials are required to conduct plotless sampling. Base maps and grid overlays are needed for planning activities, and field application generally requires only measuring tapes and data sheets. Distances should be measured with a reel tape measure, and diameter at breast height (dbh) may be determined with a diameter tape or calipers. Data sheets should be kept as simple as possible and should be reproduced on water-resistant paper or kept in a covered folder. Optional equipment includes an optical rangefinder for measuring distances and a sharp-pointed stick or steel rod to mark points and attach the measuring tape.

POINT-CENTERED QUARTER

The point-centered quarter technique is commonly used for conducting forest inventories in moderate to dense stands of woody plants that are shrub size or larger. It may also be applied in some open bunch-type grasslands where plants are not aggregated (Dix 1961, Heyting 1968, Laycock and Batcheler 1975, Smeins and Slack 1978).

The PCQ method consists of 2 independent samples: a sample of distances and a sample of tree species and dbh. Application of the technique requires a series of randomly located sample points within a sample area. The area around each sample point is divided into quarters, and the distance from the sample point to the closest tree in each quarter and its dbh are measured.

Steep slopes may require corrections of distance measurements (see Section 6.2.1). The estimates obtained by the PCQ method are considered accurate provided individual trees in a stand are randomly distributed.

Various approaches can be used to array samples (see Section 6.2.1). A grid system is used in the example in Figure 2, where each side of the sample area has been aligned along a measured compass line. For a 1-ha (2.47-acre)-square area, each side would be 100 m (110 yd) long. Corners of the sample area should be marked with stakes and flagging material, and permanent markers should be used if the area is to be sampled periodically.

Data Collection

The field procedure is as follows:

(1) Locate and mark random points on a grid map of the area (Fig. 2). To avoid confusion, check off each point on the map as it is sampled.

(2) The fastest means of locating a sample point is to use paced distances to the point. Field crew members should determine pace lengths by counting the number of steps taken along a 100-m (110-yd) transect. Repeat the count several times and take an average of the steps taken.

(3) Using the grid map as a guide, pace the distances to the first sample point.

(4) Mark the point with a stick or pointer and then divide the area around the point into quarters based on the cardinal compass directions or on the transect direction and a line perpendicular to it.

(5) Attach the measuring tape to the pointer; then measure and record the distance from the point to the closest tree in each quarter. This distance should be measured from the pointer to the center of the tree trunk or rooted base of a shrub, preferably at breast height (1.4 m, or 4.5 ft) for trees and 10 cm (4 in.) above the ground for shrubs. Note that some quarters will have no plants to measure and record.

(6) Measure the dbh of the tree with a diameter tape or calipers. For shrubs, measure crown diameter at the widest point. Large shrubs may require measuring cover circumference directly with a reel tape.

(7) Identify the plant species and record distance and dbh or cover measurements on the data sheet, as shown in Figure 3 and explained below. A blank data sheet is provided as Appendix A.

(8) Proceed to the next sample point and repeat the process.

A data sheet for recording PCQ measurements is illustrated in Figure 3, which shows data collected at 8 sample points; 50 points were sampled in the original study (Marcy 1982). In each data set, the top measurement (D) is the

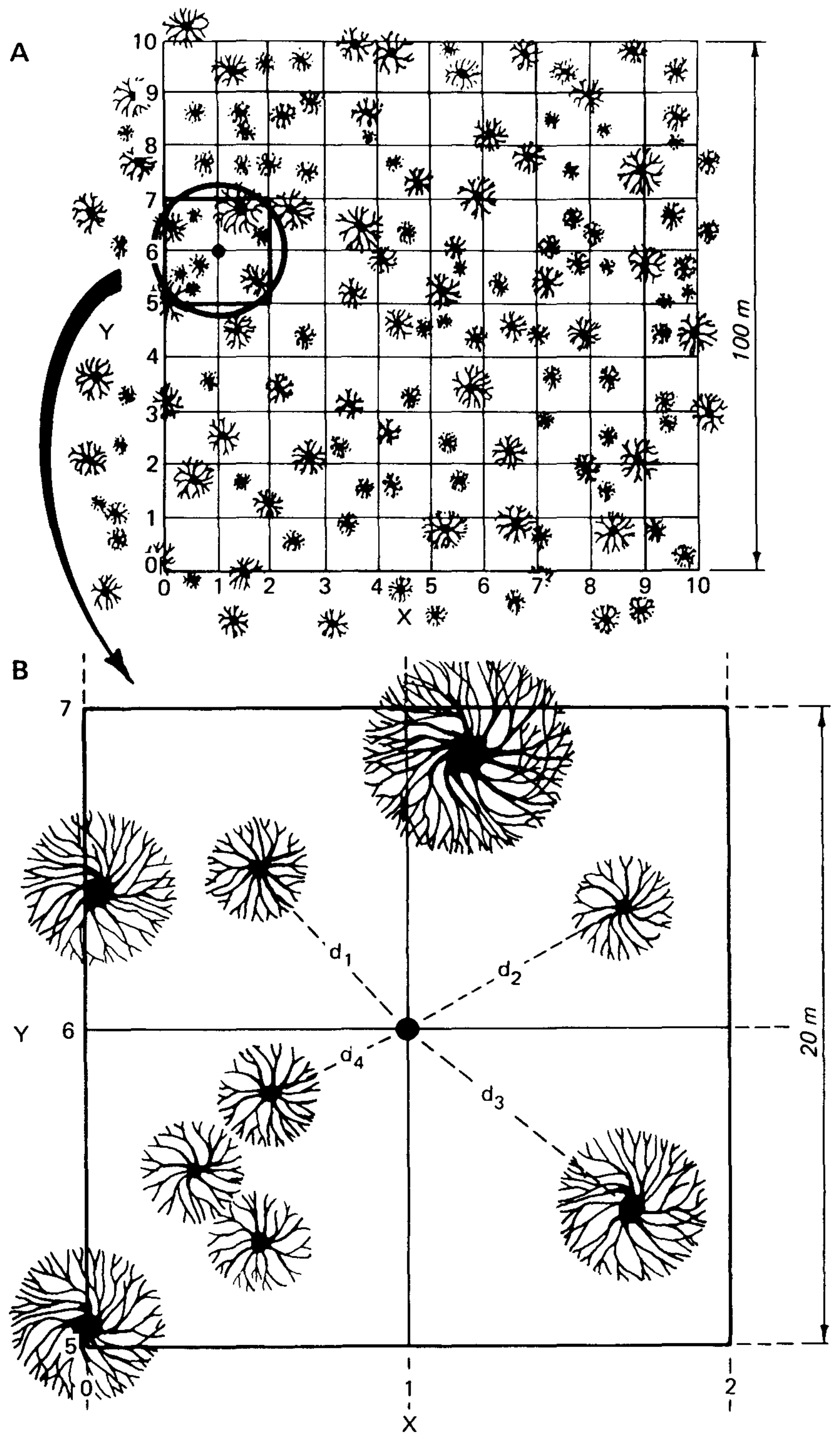


Figure 2. Selection of random sampling points from a grid map of a study area (A), and application of the point-centered quarter method showing distance measurements to the closest tree in each quarter (B). The random point selected is 1-6 (1 on the x-axis and 6 on the y-axis)

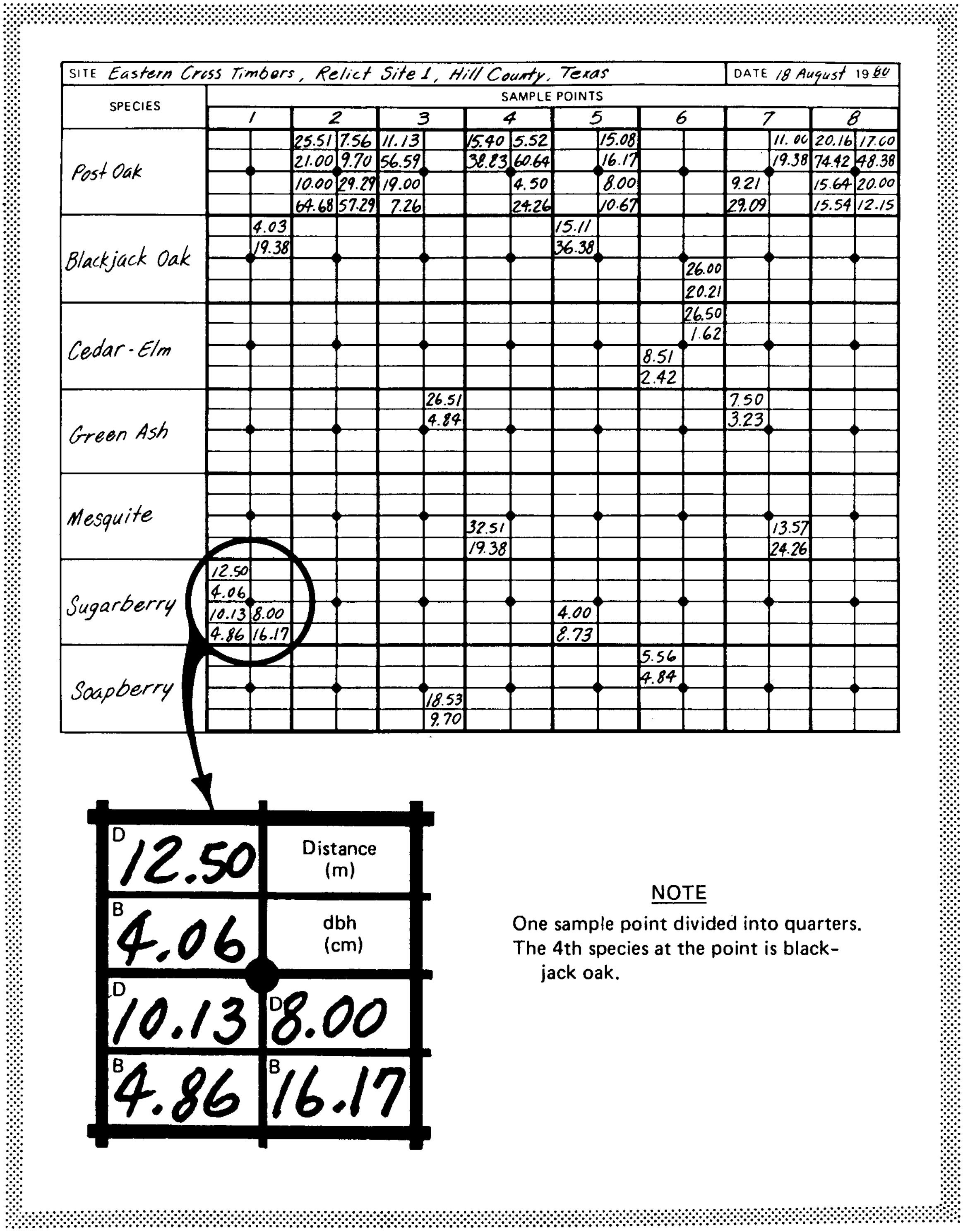


Figure 3. An example illustrating data sheet use for the point-centered quarter sampling technique (top), and enlargement showing data recorded in quarters of a sample point (bottom). Data were collected in a central-Texas woodland and represent 8 of 50 points sampled (Marcy 1982)

distance from the point to the nearest tree in that quarter, and the bottom measurement (B) is the dbh of that tree. Data in column 1 show that sugarberry (*Celtis laevigata*) occurred closest to the point in three quarters of sample point number 1; blackjack oak (*Quercus marilandica*) was the closest tree in the remaining quarter.

<u>Data Summarization</u>

The formulas needed to calculate results for the PCQ method are provided in Tables 1 and 2. Data summarization first requires averaging point-to-plant distances for all sample points to give the mean point-to-plant distance for the area (1). The mean point-to-plant distance squared gives the mean area (MA) per plant and represents the average area of ground surface available to one plant (2). Total density of plants on the area is obtained by dividing the MA into the unit area (3). These calculations for data shown in Figure 3 are given below.

(1) Mean point-to-plant distance: $\frac{462.96}{4 \times 8}$ m = 14.46 m

(2) Mean area per plant: $(14.46)^2$ = 209.31 sq m/plant

(3) Total density: $\frac{10{,}000 \text{ sq m/ha}}{209.31 \text{ sq m/plant}}$ = 47.77 plants/ha

The following attributes can now be determined using formulas 4-11 provided in Table 1: relative density, absolute density, average basal area, absolute dominance, relative dominance, frequency, relative frequency, and importance value. The dbh measurements must be converted into basal area by the formula $b = \pi(d \div 2)^2$, where b = basal area, π = 3.1416, and d = diameter; the basal areas should be totaled.

T-SQUARE NEAREST-NEIGHBOR

The T-square nearest-neighbor method (T-square) is a modification of the nearest-neighbor technique; in most cases it improves speed and efficiency. The T-square method is most suitable for use in moderately dense forest and shrub stands. Like the PCQ method, it is not appropriate for sampling plants that are highly aggregated. Slope corrections may sometimes be needed (see Section 6.2.1).

Table 1. Formulas used to summarize data from the PCQ method

MEAN POINT-TO-PLANT DISTANCE: $$\frac{\text{Total point-to-plant distances}}{4 \times \text{Number of points sampled}} \quad (1)$$

MEAN AREA PER PLANT (MA): $$(\text{Mean point-to-plant distance})^2 \quad (2)$$

TOTAL DENSITY FOR ALL SPECIES: $$\frac{\text{Unit area}}{\text{Mean area per plant}} \quad (3)$$

RELATIVE DENSITY: $$\frac{\text{Number of individuals of a species}}{\text{Total number of individuals of all species}} \times 100 \quad (4)$$

ABSOLUTE DENSITY OF A SPECIES:

$$\frac{\text{Relative density of a species}}{100} \times \text{Total density of all species} \quad (5)$$

BASAL AREA OF A SPECIES: Sum of basal areas

AVERAGE BASAL AREA OF A SPECIES: $$\frac{\text{Total basal area of a species}}{\text{Number of individuals of a species}} \quad (6)$$

ABSOLUTE DOMINANCE (PER UNIT AREA) OF A SPECIES:

$$\text{Absolute density of a species} \times \text{Average basal area of a species} \quad (7)$$

RELATIVE DOMINANCE: $$\frac{\text{Absolute dominance of a species}}{\text{Total absolute dominance of all species}} \times 100 \quad (8)$$

FREQUENCY: $$\frac{\text{Number of points at which a species occurs}}{\text{Total number of points sampled}} \times 100 \quad (9)$$

RELATIVE FREQUENCY: $$\frac{\text{Frequency of a species}}{\text{Total frequencies of all species}} \times 100 \quad (10)$$

IMPORTANCE VALUE OF A SPECIES:

$$\text{Relative density} + \text{Relative dominance} + \text{Relative frequency} \quad (11)$$

Table 2. Calculations using data from Figure 3

Species	Relative Density	Absolute Density	Average Basal Area (sq cm)	Absolute Dominance	Relative Dominance	Frequency	Relative Frequency	Importance Value
Post oak	$\frac{17}{32} \times 100$ = 53.12	$\frac{53.12}{100} \times 48$ = 25.50	$\frac{21,122.96}{17}$ = 1242.53	25.50 × 1242.53 = 31,684.51	$\frac{31,684.51}{35,936.48} \times 100$ = 88.17	$\frac{6}{8} \times 100$ = 75.00	$\frac{75.00}{225.00} \times 100$ = 33.33	53.12 88.17 +33.33 = 174.62
Blackjack oak	$\frac{3}{32} \times 100$ = 9.38	$\frac{9.38}{100} \times 48$ = 4.50	$\frac{1655.25}{3}$ = 551.75	4.50 × 551.75 = 2482.87	$\frac{2482.87}{35,936.48} \times 100$ = 6.91	$\frac{3}{8} \times 100$ = 37.50	$\frac{37.50}{225.00} \times 100$ = 16.66	9.38 6.91 +16.66 = 32.95
Cedar-elm	$\frac{2}{32} \times 100$ = 6.25	$\frac{6.25}{100} \times 48$ = 3.00	$\frac{6.65}{2}$ = 3.32	3.00 × 3.32 = 9.96	$\frac{9.96}{35,936.48} \times 100$ = 0.03	$\frac{1}{8} \times 100$ = 12.50	$\frac{12.50}{225.00} \times 100$ = 5.55	6.25 0.03 +5.55 = 11.83
Green ash	$\frac{2}{32} \times 100$ = 6.25	$\frac{6.25}{100} \times 48$ = 3.00	$\frac{26.59}{2}$ = 13.29	3.00 × 13.29 = 39.87	$\frac{39.87}{35,936.48} \times 100$ = 0.11	$\frac{2}{8} \times 100$ = 25.00	$\frac{25.00}{225.00} \times 100$ = 11.11	6.25 0.11 +11.11 = 17.47
Mesquite	$\frac{2}{32} \times 100$ = 6.25	$\frac{6.25}{100} \times 48$ = 3.00	$\frac{757.22}{2}$ = 378.61	3.00 × 378.61 = 1135.83	$\frac{1135.83}{35,936.48} \times 100$ = 3.16	$\frac{2}{8} \times 100$ = 25.00	$\frac{25.00}{225.00} \times 100$ = 11.11	6.25 3.16 +11.11 = 20.52
Sugarberry	$\frac{4}{32} \times 100$ = 12.50	$\frac{12.50}{100} \times 48$ = 6.00	$\frac{296.69}{4}$ = 74.17	6.00 × 74.17 = 445.02	$\frac{445.02}{35,936.48} \times 100$ = 1.23	$\frac{2}{8} \times 100$ = 25.00	$\frac{25.00}{225.00} \times 100$ = 11.11	12.50 1.23 +11.11 = 24.84
Soapberry	$\frac{2}{32} \times 100$ = 6.25	$\frac{6.25}{100} \times 48$ = 3.00	$\frac{92.28}{2}$ = 46.14	3.00 × 46.14 = 138.42	$\frac{138.42}{35,936.48} \times 100$ = 0.38	$\frac{2}{8} \times 100$ = 25.00	$\frac{25.00}{225.00} \times 100$ = 11.11	6.25 0.38 +11.11 = 17.74

Data Collection

After sampling points have been designated, the following field procedure (Fig. 4) is applied:

(1) Mark the sample point (Pt) with a metal rod or stick and determine which tree is closest to the point (Cp). This may be done by visual inspection or by distance measurements if 2 or more plants are in question.

(2) After C_p has been determined, attach a tape measure to the stake and record the distance to the center of the tree. Measure and record the dbh and species. If shrubs are sampled, measure crown diameter at the widest point.

(3) Use a compass with a sighting device to establish the 180-deg exclusion angle at 90 deg to a line joining Pt and C_p.

(4) Locate the nearest neighbor (N_n) to C_p outside the exclusion angle; measure and record the distance to N_n and its dbh and species.

The sample data sheet shown as Figure 5 provides a column for listing species and rows for recording distance and dbh measurements by sample point. Under the heading Sample Points, the distance from the sampling point to the closest plant should be recorded in the first column, and the nearest-neighbor distance should be recorded in the second column. The dbh measurements should be recorded under their respective distance measurements. A blank data sheet suitable for reproduction is provided as Appendix B.

Data Summarization

The data provided in Figure 5 represent 16 sample points that are used in the following calculation of plant density. The equation for calculating density is as follows:

$$D = \frac{\sqrt{2} \times n}{\pi\left[\left(\Sigma d_1^2\right)\left(\Sigma d_2^2\right)\right]^{1/2}} \qquad (12)$$

where:

D = density (the number of individuals per unit area, in the square of the units used to measure distance)

n = number of random points sampled

π = 3.1416

d_1 = point-to-plant distance

d_2 = plant-to-plant distance

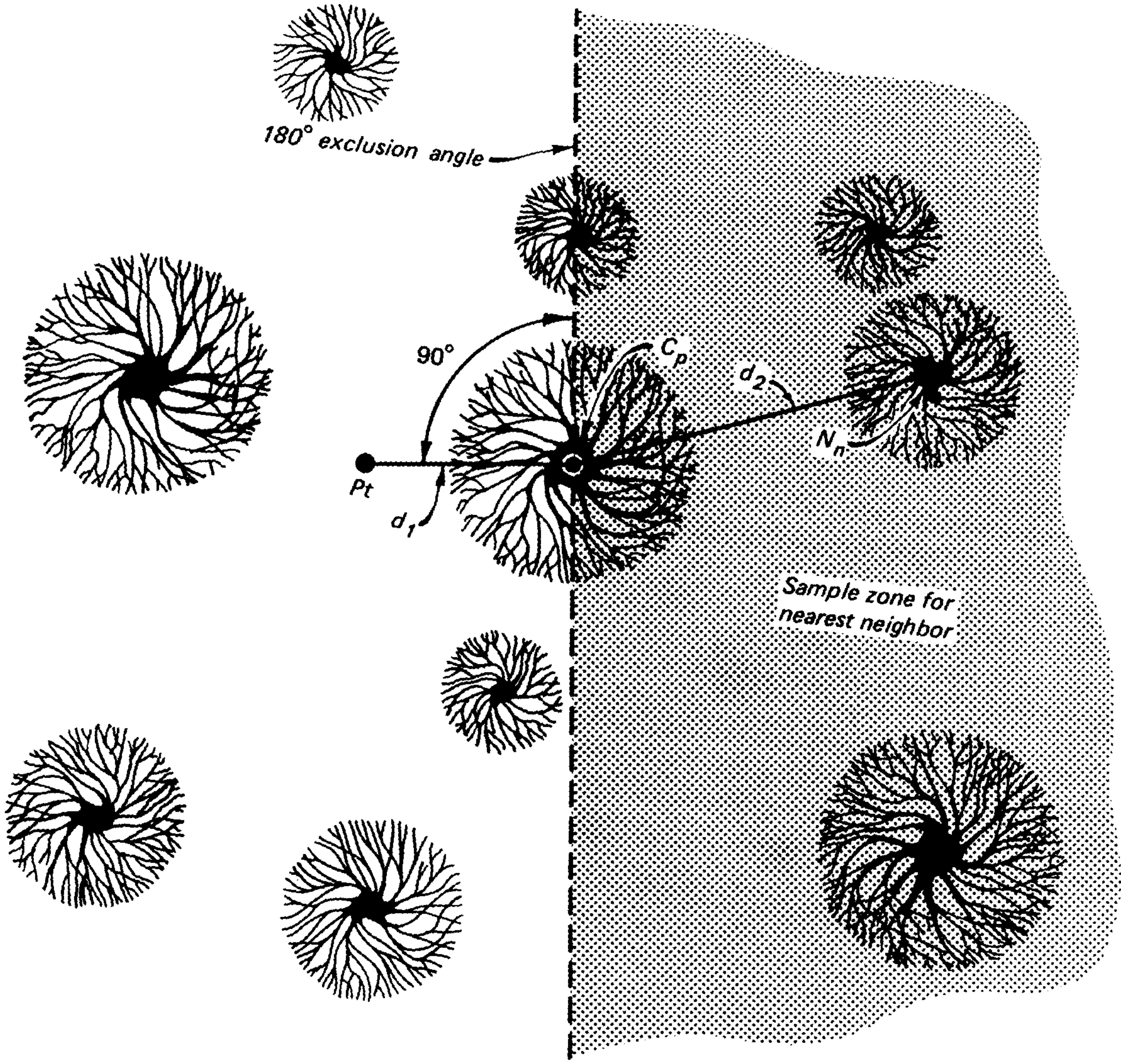


Figure 4. Application of the T-square nearest-neighbor method (adapted from Hays et al. 1981)

Example 1 illustrates the calculation of density using data from Figure 5. Equations 4-11, presented in the discussion of the PCQ technique, can be used to derive other summary statistics.

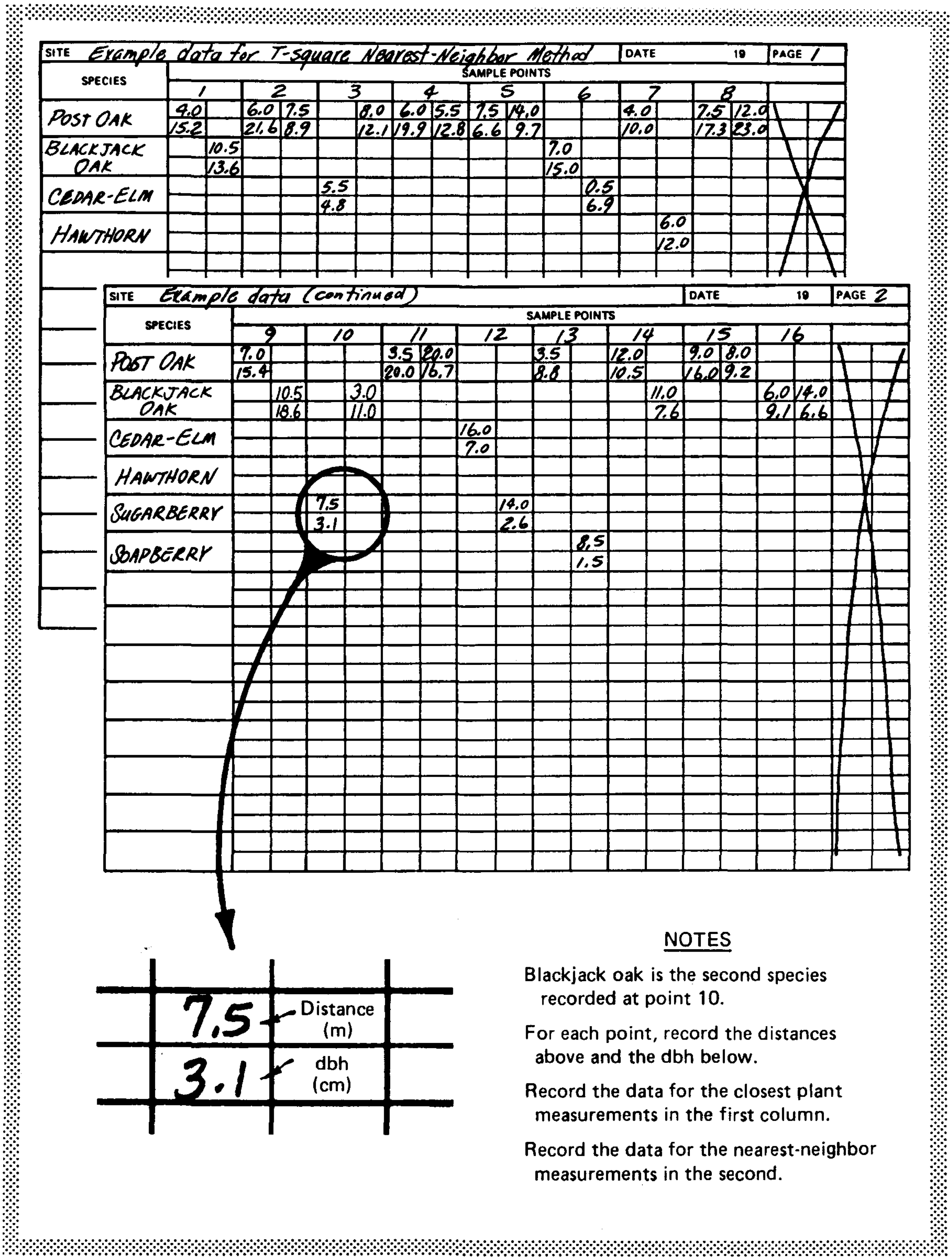


Figure 5. Data sheets for the T-square nearest-neighbor method showing how data are recorded

Example 1

Calculation of Density Using the T-Square Nearest-Neighbor Method

The distances to the closest plant and the nearest-neighbor for each species are squared and summed separately. Post oak occurred 11 times as the plant closest to the sample point and 7 times as the nearest neighbor. Calculation of distances for post oak is as follows:

$$\Sigma d_1^2 = 4^2 + 6^2 + 6^2 + 7.5^2 + 4^2 + 7.5^2 + 7^2 + 3.5^2 + 3.5^2 + 12^2 + 9^2$$

$$= 515.0$$

$$\Sigma d_2^2 = 7.5^2 + 8^2 + 5.5^2 + 14^2 + 12^2 + 20^2 + 8^2 = 954.5$$

Σd_1^2 and Σd_2^2 for all species are as follows:

Species	Σd_1^2	Σd_2^2
Post oak	515.0	954.4
Blackjack oak	85.0	546.5
Cedar-elm	286.3	0.3
Hawthorn	0.0	36.0
Sugarberry	56.3	196.0
Soapberry	0.0	72.3
Total	942.6	1805.5

Applying the values 942.6 and 1805.6 in Equation 12,

$$D = \frac{\sqrt{2} \times 16}{3.1416\ [(942.6)(1805.6)]^{1/2}}$$

$$D = \frac{22.6275}{3.1416\ (1304.59)}$$

$$D = 0.00552 \text{ tree/m}^2$$

To determine the density, or number of trees/ha:

$$D = 0.00552 \text{ tree/m}^2 \times 10{,}000 \text{ m}^2\text{/ha}$$

$$D = 55.2 \text{ trees/ha}$$

JOINT-POINT

The joint-point or joint-neighbor technique is used to estimate density of aggregated trees and shrubs. The joint-point technique is similar to the T-square in application. However, 3 distance measurements are taken: d_1 = distance from the sample point (Pt) to the closest plant (C_p); d_2 = distance from C_p to the nearest neighbor plant (N_n); and d_3 = distance from N_n to the second nearest neighbor (N_m) (Fig. 6). Because long distances are often recorded, it may be necessary to correct for the effect of slope.

When the PCQ and T-square methods are applied to aggregated populations (clumped individuals), sample points are more likely to fall between isolated individuals than between very close neighbors. Therefore, the average distance measured will be large, and the estimate of density will be low. The joint-point technique accurately estimates density of aggregated populations by including a point distance and two nearest-neighbor distance measurements, and, in effect, samples for closely spaced individuals.

Data Collection

With the joint-point technique, it is necessary to set the limit distance, R (the maximum search distance for the nearest neighbor and second nearest neighbor). This factor can be determined by arranging pilot study point distances in ascending order and locating the middle point (R) or by correcting field data after they are collected (see Data Summarization below). In Table 3, R is 6.0, which is the 44th of 88 point distances. The nearest-neighbor distances are then measured, as given below, only if they are less than or equal to R .

The procedure for measuring nearest-neighbor distances is outlined below. A sample data sheet is provided as Appendix C.

(1) Locate one point and mark it with a stick or metal rod.

(2) Locate the closest plant visually, or with a tape measure if two or more plants are in question.

(3) Measure and record the distance to C_p . Measure to the approximate center of a tree at 4.5 ft (1.4 m) above the ground. Record the dbh and species. Determine slope angle.

(4) Locate the nearest neighbor to C_p ; measure and record the distance, dbh, and species. Determine slope angle.

(5) Locate the second nearest neighbor from N_n ; measure and record the distance, dbh, and species. Determine slope angle.

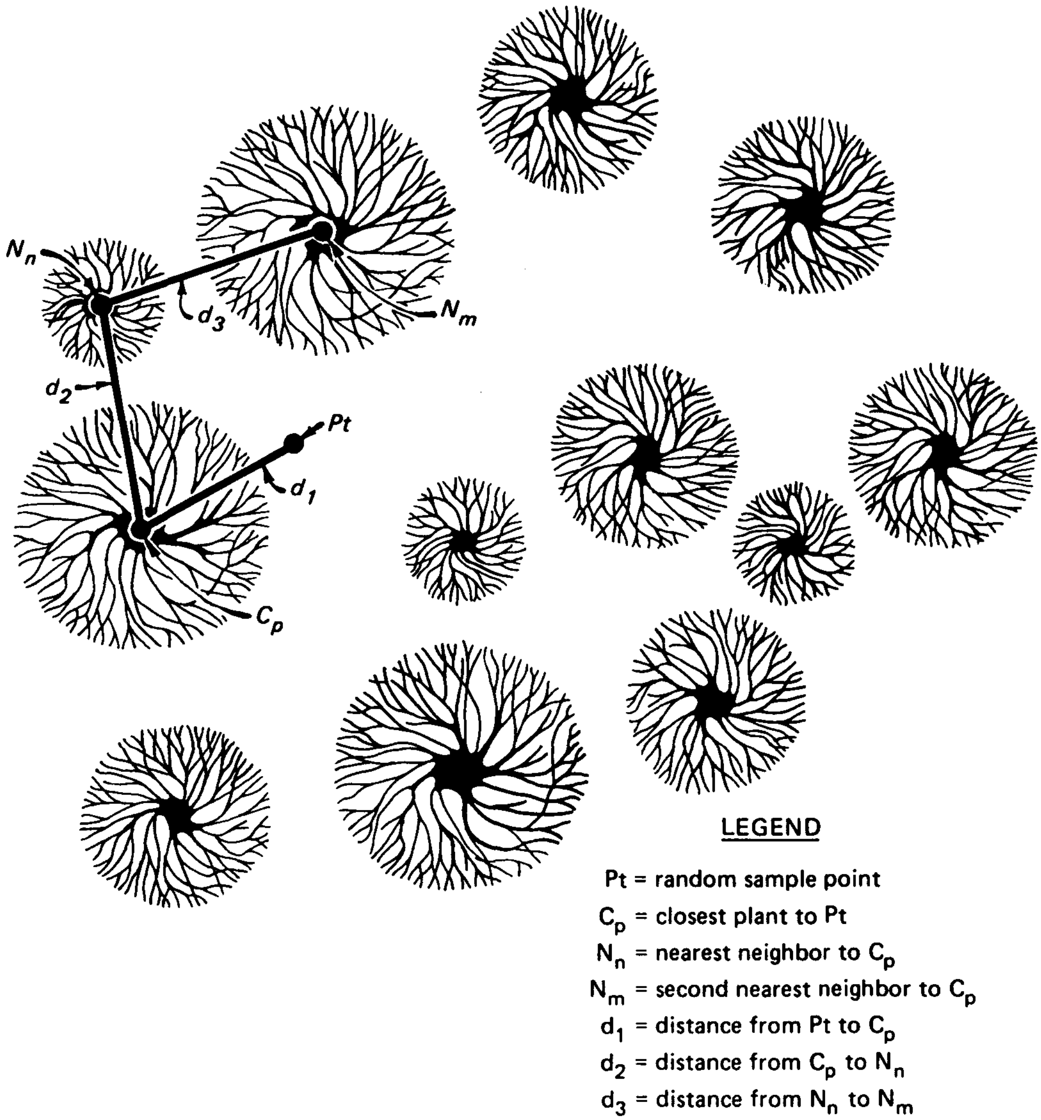


Figure 6. Application of the joint-point nearest-neighbor method

Data Summarization

The point, nearest-neighbor, and second nearest-neighbor distances should be arranged in ascending order of size. The point distances should be inspected to determine the limit R , which is equal to or greater than half the point distances (Table 3). Batcheler (1971) found that by using half of the point distances, the joint-point method was generally more accurate than if all point distances were used. The estimate obtained using half of the point distances is termed the 50% Point Distance Estimate (50% PDE). If more than half of the point distances were used, random population estimates were high and biased, whereas estimates of aggregated populations were low and

Table 3. Joint-point nearest-neighbor method of tabulating distance data for computation of density*

	Upper Limit								
	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0
	Sample Point Distance								
	0.5	2.5	4.5	6.5	9.0	10.5	14.0	15.0	17.0
	0.5	2.5	4.5	6.5	9.0	10.5		16.0	
	1.0	2.5	4.5	6.5	9.0	11.0		16.0	
	1.0	2.5	5.0	7.0	9.0	11.0			
	1.5	3.0	5.0	7.0	9.0	12.0			
	1.5	3.0	5.0	7.0	9.0				
	2.0	3.0	5.0	7.0	9.0				
	2.0	3.0	5.5	7.5	9.0				
	2.0	3.5	6.0	7.5	9.0				
		3.5	6.0	7.5	9.0				
		3.5	6.0	7.5	9.5				
		3.5	6.0**	8.0	10.0				
		3.5	6.0	8.0	10.0				
		4.0	6.0	8.0	10.0				
		4.0	6.0	8.0	10.0				
		4.0			10.0				
		4.0							
		4.0							
		4.0							
		4.0							
		4.0							
		4.0							
		4.0							
Accumulated									
n	9	32	47	62	78	83	84	87	88
Σrp	12.0	91.5	172.5	282.0	431.5	486.5	500.5	547.5	564.5
Σrp^2	19.0	301.25	744.25	1548.0	2858.0	3464.5	3660.5	4397.5	4686.5

**R = 6.0 (1/2 of 88 sample points = 44; 44th value = 6.0)

Nearest-Neighbor Distance

Accumulated											
n	9	25	37	48	66	74	79	82	86	87	88
Σrn	29	115	202	305	510.5	618.5	696.0	749	828.5	851.0	876.5

* Hypothetical data.

biased. Batcheler (1971) concluded that when point distances were greater than nearest-neighbor distances (as in aggregated populations), the density estimate would be low, and when point distances were equal to or smaller than nearest-neighbor distances, the estimate would be high. A correction factor was derived to adjust the 50% PDE up or down depending on population characteristics (Batcheler 1971).

The equation used to calculate density of a randomly distributed population (Batcheler 1971) is as follows:

$$D = n \div \pi \; [r_1^2 + r_2^2 + \ldots + r_n^2 + (N - n)\, R^2] \qquad (13)$$

where:

D = density (50% PDE)

n = number of distances $\leq R$

$r_1^2 + r_2^2 + \ldots + r_n^2$ = sum of the point distances squared $\leq R$

R = value of the middle point distance (limit distance)

N = total number of points sampled

Example 2 shows density calculations using data derived from a random population containing 152 trees on an area equivalent to 2.56 ha (6.32 acres). Figure 7 illustrates a portion of the data used in the example.

The following equation incorporates a correction factor that should be used with data derived from a population with 1 degree of aggregation:

$$\log \lambda = \log D - (0.1416 - 0.1613\ \Sigma rp/\Sigma rn) \qquad (14)$$

where:

λ = corrected density estimate

D = 50% PDE (corrected for slope if necessary)

Σrp = sum of the point distances $\leq R$

Σrn = sum of the nearest-neighbor distances $\leq R$

When it is evident that a second degree of aggregation exists in a population, $\Sigma rp \div \Sigma rm$ (sum of second nearest-neighbor distances $\leq R$) becomes the appropriate correction factor to be substituted for $\Sigma rp \div \Sigma rn$ in Equation 14 above. If a third-order aggregation is suspected, it is necessary to include third nearest-neighbor distances in the sample and adjust Equation 14.

Example 2

Calculation of Density Using the Joint-Point Method

Table 3 shows the joint-point distances from a set of hypothetical data arranged in ascending order of size. The limit R is equal to the middle point distance. The nearest-neighbor and second nearest-neighbor distances should be similarly arranged. Data from sampling the nearest-neighbor (N_n) are summarized at the bottom of Table 3. Eighty-eight points were sampled from a random population of 152 trees in an area equivalent to 2.56 ha. Using Equation 13, the calculation of density is as follows:

$$D = 44 \div 3.1416\ [636.25 + (88 - 44)\ 6.0^2]$$
$$D = 44 \div 3.1416\ (2220.25)$$
$$D = 44 \div 6975.13$$
$$D = 0.0063081 \text{ trees/m}^2$$

Converting to hectares,

$$D = 0.0063081 \text{ trees/m}^2 \times 10{,}000 \text{ m}^2\text{/ha}$$
$$D = 63.08 \text{ trees/ha, or } 63 \text{ trees/ha}$$

Using the density determined for sample data,

Population = 63 trees/ha × 2.56 ha = 161 trees

To correct for the effect of slope on the density estimate, all cosines of the measured slope angles (Fig. 7) should be summed and averaged. The average of the cosines of slope angles for data presented in Table 3 is 0.99201, and the corrected 50% PDE is as follows:

Corrected D = (50% PDE) (1 ÷ mean cosine of the slope angles)
D = (63 trees/ha)(1 ÷ 0.99201)
D = (63 trees/ha)(1.0080)
D = 63.5 trees/ha or approximately 64 trees/ha.

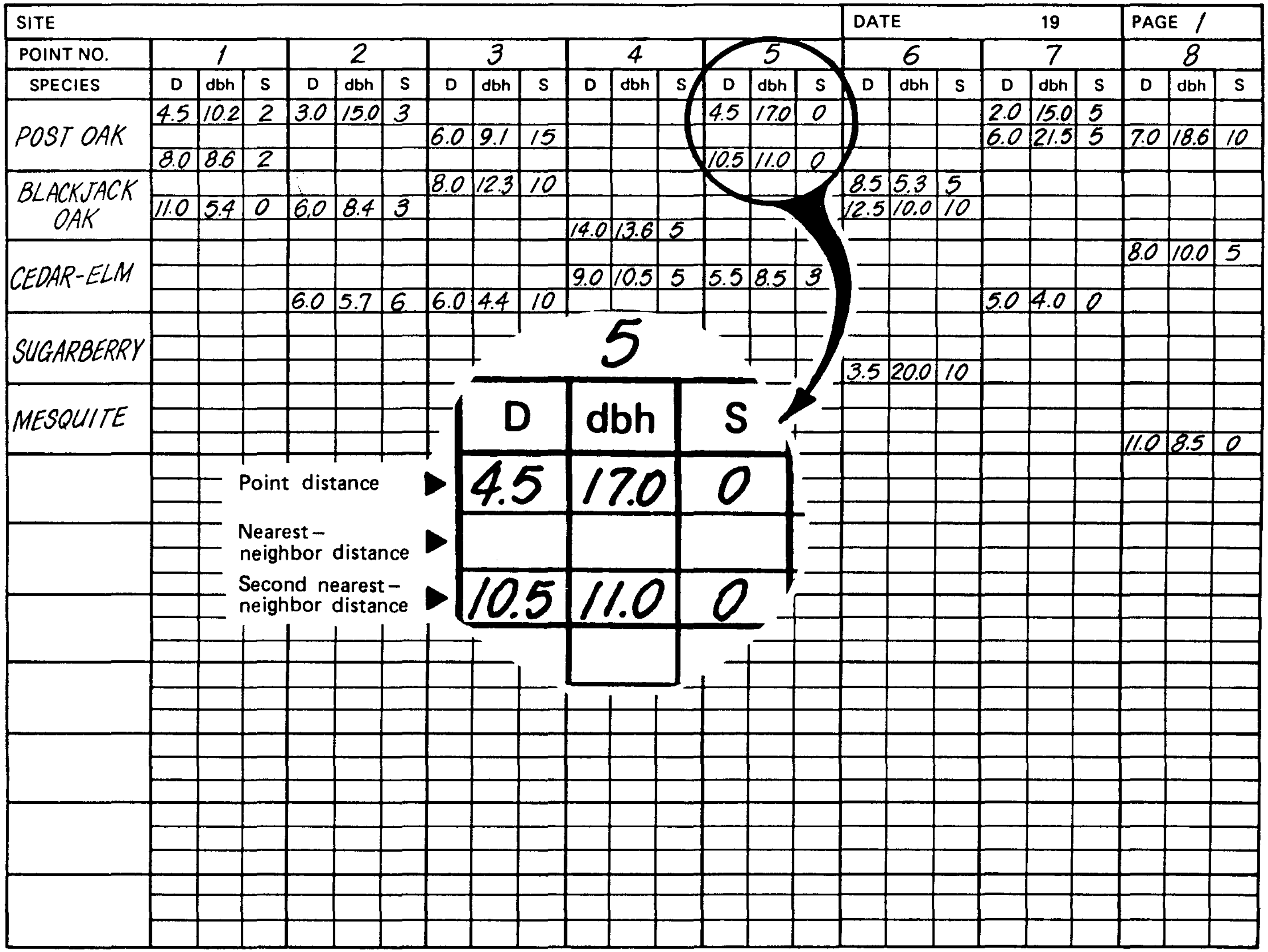
Population = 64 trees/ha × 2.56 ha = 164 trees

Assume that 1 degree of aggregation exists in the population. Using Equation 14, the corrected density estimate would be calculated as follows:

$$\log \lambda = \log 64 - [0.1416 - (0.1613 \times 136.5/275)]$$
$$\log \lambda = \log 64 - (0.1416 - 0.0800)$$
$$\log \lambda = \log 64 - 0.0616$$
$$\log \lambda = 1.80618 - 0.0616$$
$$\log \lambda = 1.7446$$
$$\lambda = \text{antilog } 1.7446$$
$$\lambda = 55.55, \text{ or } 56 \text{ trees/ha}$$

Population = 56 trees/ha × 2.56 ha = 143 trees

The population contained 152 trees or 59 trees/ha. The density values calculated above are within 8.5% and 5.0%, respectively, of the true density.



SITE | DATE 19 | PAGE 1

POINT NO.	1			2			3			4			5			6			7			8		
SPECIES	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S
POST OAK	4.5	10.2	2	3.0	15.0	3							4.5	17.0	0				2.0	15.0	5			
							6.0	9.1	15										6.0	21.5	5	7.0	18.6	10
	8.0	8.6	2										10.5	11.0	0									
BLACKJACK OAK							8.0	12.3	10							8.5	5.3	5						
	11.0	5.4	0	6.0	8.4	3										12.5	10.0	10						
										14.0	13.6	5												
CEDAR-ELM																						8.0	10.0	5
										9.0	10.5	5	5.5	8.5	3									
				6.0	5.7	6	6.0	4.4	10										5.0	4.0	0			
SUGARBERRY																								
																3.5	20.0	10						
MESQUITE																								
																						11.0	8.5	0

Figure 7. Illustration of data sheet use for the joint-point nearest-neighbor method (D = distance measurement, dbh = diameter at breast height, S = slope angle)

A uniform population should include all point and nearest-neighbor distances with no limit R .

TECHNIQUES EVALUATION

Example 3 illustrates the approach used to compare sampling efficiency and accuracy of two methods tested in a pilot study. In this case, a hypothetical population was used rather than actual pilot study data. Note that in the example the PCQ Method required fewer samples but was slightly less accurate than the T-square method.

Pilot study data can also be used to test aggregation. Equations 15, 16, and 17 provide the equations and criteria that are employed to determine if full joint-point sampling is necessary. If aggregation is detected, these same pilot data can be used to set the limit distance (R) for subsequent sampling.

Population characteristics (degree of randomness or aggregation) (Batcheler 1973) can be determined as follows:

$$\Sigma rp \div \Sigma rn = \begin{cases} 0.83 - 0.90 & \text{for a random population} \\ 0.58 - 0.71 & \text{for a uniform population} \\ 0.37 - 0.41 & \text{for a perfectly uniform population} \end{cases} \tag{15}$$

$$\Sigma rp \div 0.88\ \Sigma rn \quad \text{(provides an index of 1st degree aggregation with an expectation of 1.0)} \tag{16}$$

$$\Sigma rp \div 0.88\ \Sigma rm \quad \text{(provides an index of 2nd degree aggregation or total departure from randomness with an expectation > 1.0)} \tag{17}$$

where:

Σrp = sum of point distances

Σrn = sum of nearest-neighbor distances

Σrm = sum of second nearest-neighbor distances

If $\Sigma rp \div 0.88\ \Sigma rn = \Sigma rp \div 0.88\ \Sigma rm$, the distance measurements to the second nearest-neighbor can be omitted, thus saving field time.

Example 3

Comparison of Sample Size Requirements and Accuracy of the T-Square and PCQ Methods

Data are from a hypothetical population of 152 random trees that were sampled in an area equivalent to 2.56 ha. A presample of 40 points using the T-square method gave a mean distance ($\bar{x}$) of 8.14 m and variance (s^2) of 20.89. The PCQ method gave a mean distance of 13.19 m and variance of 46.24. The calculation of sample size for both methods to be within 10% of the mean, $\alpha = 0.10$ and t-value = 1.66 , is as follows:

$$\text{Sample size } n = \frac{(\text{t-value})^2\ (s^2)}{[(\%\ \text{change})\ (\bar{x})]^2} \div \begin{array}{l}\text{number distances}\\ \text{per sample point}\end{array}$$

$$\text{T-square } n = \frac{(1.66)^2\ (20.89)}{[0.10\ (8.14)]^2} \div 2$$

$$n = 43.5, \text{ or } 44 \text{ points}$$

$$\text{PCQ } n = \frac{(1.66)^2\ (46.24)}{[0.10\ (13.19)]^2} \div 4$$

$$n = 18.3, \text{ or } 19 \text{ points}$$

The T-square sample size is approximately 2.4 times larger than the PCQ sample size. Accuracy of the T-square and PCQ methods was compared by sampling 44 and 19 random points, respectively. Solving for D in Equation 12 (Σd_1^2 = (2103, Σd_2^2 = 5383.75) gives an estimate of 58.86 trees/ha; therefore, using the T-square method, the total number of trees on the 2.56-ha area would be 150.68, or 151.

Equations for the PCQ method are found in the discussion of Point-Centered Quarter. The calculations are as follows:

$$\text{Mean area} = (13.19)^2 = 173.98\ m^2/\text{tree}$$

$$D = 10{,}000\ m^2/\text{ha} \div 173.98\ m^2/\text{tree}$$

$$D = 57.4, \text{ or } 57 \text{ trees/ha}$$

The total population would equal 57 trees/ha × 2.56 ha, or 146 trees. The area actually contained 152 trees; therefore, the T-square and PCQ methods were within 1% and 4%, respectively, of the known population.

PERSONNEL REQUIREMENTS

Distance sampling techniques can be used by one individual without undue loss of efficiency (Cottam and Curtis 1956). However, a team of two, in which one person records data and locates points and the other measures distances and dbh, is probably more efficient since the chief limitation to speed is the necessity for stopping to record data (Cottam and Curtis 1956, Fletcher 1983).

The amount of time required to use distance methods depends upon (1) familiarity with the method and vegetation, (2) size of the sampling crew, (3) stand density, (4) topography, and (5) habitat type (e.g., upland, bottomland, swamp). A large proportion of time is spent locating the sample points and determining the relative position of plants (nearest neighbor) at each point.

Marcy (1982) found that dense saplings and shrubs increase sampling time and hinder distance measurements. For example, a 1-ha sample area in central Texas required approximately 8 to 10 hours for sampling 50 points using the PCQ technique. Sampling efficiency would have been greater if a 2-member crew had been used. Other examples are given in Table 4. The time for sampling dense saplings and shrubs can be decreased by sampling understory vegetation with small plots used in conjunction with plotless techniques for trees.

CAUTIONS AND LIMITATIONS

The major sources of error in distance sampling are (1) failure to select truly random sample points, and (2) mismeasurement of distances to the appropriate plants (Ashby 1972, Hays et al. 1981). Cottam and Curtis (1956) found that researchers have a tendency to subconsciously place sampling points so that large or unusual trees occur in the sample more commonly than they occur in the stand. This bias is minimal when distance methods are used because it is difficult to place a point so that 2 or more trees at a point can be predetermined.

The basic assumption behind distance sampling methods is that individual trees of all species are randomly dispersed (Smeins and Slack 1978). When trees are noticeably clumped, with more open spaces between clumps, the PCQ and T-square methods will not give accurate density estimates (Cottam and Curtis 1956, Hays et al. 1981). Aggregation causes underestimation of total density due to sampling points having a greater probability of falling between

Table 4. Estimate of time required to apply the point-centered quarter technique in various habitat types

Study	Habitat Type	Stand Density per Hectare	No. of Points	Time per Point (minutes)
Lindsey 1956 (Indiana, with 2-man crew)	Beech/white oak woodland	304	38	1.5
Marcy 1982 (Texas, with 1-man crew)	Oak woodland	706	40	12
	Cedar-elm woodland	517	50	9.6
	Mesquite/cedar-elm parkland	369	50	12
	Riparian woodland	319	100	8.4
	Pecan parkland	60	50	10.8
Fletcher 1983 (Louisiana, with 2-man crew)	Brackish marsh			
	Upland	570	16	28.0
	Transition	355	12	31.5
	Bald cypress-tupelo-gum swamp			
	Upland	1095	12	16.8
	Transition	1150	18	18.4
	Wetland	1830	8	23.8

clumps than within clumps. By falling between clumps, the point-to-plant distances will be longer and give an overestimate of mean area per individual and thus an underestimate of density (Mueller-Dombois and Ellenberg 1974). Therefore, the joint-point nearest-neighbor method is recommended where 2 or 3 levels of contagion (clumping) occur (Batcheler and Bell 1970).

Distance methods cannot be used to accurately estimate the density of widely spaced individuals because it may be extremely difficult to locate points in a stand without sampling the same tree twice. When trees are widely spaced, it may be more efficient to count and measure all trees in the stand. It is acceptable to measure distances to closest trees that lie outside the sample area boundaries; however, sample points should not be located outside the boundaries (Clark and Evans 1954).

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APPENDIX A

BLANK DATA SHEET THAT CAN BE USED FOR THE POINT-CENTERED QUARTER TECHNIQUE

SITE								DATE 19__	PAGE
SPECIES	SAMPLE POINTS								

APPENDIX B

BLANK DATA SHEET THAT CAN BE USED FOR THE T-SQUARE NEAREST-NEIGHBOR TECHNIQUE

SITE													DATE 19				PAGE	
SPECIES	SAMPLE POINTS																	

APPENDIX C

BLANK DATA SHEET THAT CAN BE USED FOR THE JOINT-POINT NEAREST-NEIGHBOR TECHNIQUE

SITE																DATE				19		PAGE		
POINT NO.																								
SPECIES	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S	D	dbh	S