



An Improved Method of Obtaining Density from Line-Transect Data

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the microscope and all pollen is identified and tabulated (Davis 1965a). For counts of fossil material, for example, a microscope can be used with specially constructed ocular diaphragms that block off a portion of the field of view; the remaining field should be an integral fraction of a millimeter (e.g., 0.5 mm) in diameter at the magnification used for counting. The slide is then advanced the width of the field (e.g., 0.5 mm) after each sweep across the slide by means of the calibrated mechanical stage. Several slides are prepared using the same size measured volume, and each is counted. The total number of grains in the original suspension is extrapolated from the mean number of grains counted per slide, and a confidence interval for the estimate is calculated using the variance of the counts. Results of experiments testing the reliability of estimates made in this way are given in the earlier paper (Davis 1965a). Separate estimates of absolute frequency can be made for each pollen type, as they have been tabulated separately, and the same counts can be used also for calculation of percentage values within the total pollen count.

After sufficient material for quantitative slides has been subtracted from the tertiary butyl alcohol suspension, the remainder can be concentrated for storage by centrifugation or filtration. Silicone fluid added to the concentrate will protect the pollen from desiccation when all the alcohol evaporates.

In my earlier description of this technique I advocated splitting the prepared sample into several fractions which were differentially diluted for storage, on the one hand, and counting, on the other. Although this can be done accurately, there is no control provided to assure that it is done accurately every time. I now prefer to use a single suspension of the sample, with the variance of counts providing an estimate of the thoroughness with which the sample was mixed in the suspending fluid and

the accuracy with which pipetting was done. The more important modification, however, is the use of tertiary butyl alcohol instead of benzene. Benzene is non-polar, and pollen grains suspended in it, which are apparently charged, stick to glass and to one another, particularly in the presence of even very small amounts of water. In alcohol, however, the pollen disperses readily and rinses easily from glass surfaces. It is therefore no longer necessary to use extreme care in drying glassware, or in dehydrating the pollen sample. Further, the relatively high viscosity of the alcohol obviates the need for adding a measured quantity of silicone fluid to the suspending fluid before subtracting measured portions. This saves time and permits greater variation in the volumes that can be removed from the suspension and placed on a single microscope slide. Tertiary butyl alcohol is far less volatile and somewhat less toxic than benzene, but considerable care must still be taken to avoid breathing fumes. Both sample dilution and slide preparation should be done using a fume hood.

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AN IMPROVED METHOD OF OBTAINING DENSITY FROM LINE-TRANSECT DATA

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Abstract. Measurements are taken perpendicular to the transect across the greatest extent of each intercepted plant. The sum of the reciprocals of these measurements is multiplied by the desired unit-area and divided by the length of the transect to obtain the density statistic. The relationship of this method to that of McIntyre (1953) is discussed, and the stratified random sampling pattern is suggested in preference to a single long transect.

INTRODUCTION

The speed and convenience of the line-transect method of vegetational measurement make it a desirable tool for determining the density statistic. The method proposed here is a variation of that of McIntyre (1953), differing from his in the measurement employed. Two reasons for presenting this method are: the derivation of McIntyre's technique is inaccessible to anyone lacking knowledge of integral calculus and statistics, whereas the present method's derivation can be apprehended visually and logically; and this method obviates the necessity of the correction factors employed by McIntyre.

METHOD

Consider an area, $A = LW$ (L = length, W = width), such as that shown in Fig. 1A, the contained plants being

arranged edge to edge, without overlap, so as to exactly stretch across W . It is clear that any number of sub-transects of length L , parallel to L , must intercept just one plant per transect. Conversely, the total transect length (the sum of the sub-transects) divided by the number of interceptions must be equal to L . Note that L can intercept one plant per transect only if there are no gaps or overlaps between the plants. The number of plants contained in A can be determined by dividing W by the average of the width measurements, M (measured as shown in Fig. 1C) of the intercepted plants. Now, if these plants were re-arranged, without rotation, as in Fig. 1B, so that they no longer lay in a chain across W , and if a large number of sub-transects were again laid down parallel to L , the total transect length divided by the number of interceptions, N , must approximate L .

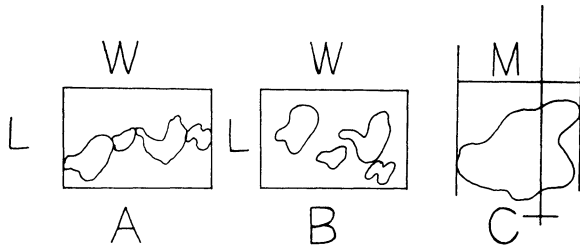


FIG. 1. A) Portion of an ideal population showing that if L is the length intercepting one plant on the average, then the enclosed plants can exactly span W . B) Portion of the ideal population as it might naturally occur. C) Manner in which M is measured. Inverted T represents transect.

The number of empty transects will, on the average, be equalled by the number of multiple interceptions on the other transects. The number of plants contained can be determined as before.

In the field the measurement M can be readily determined for each plant as the greatest width perpendicular to the transect, and the average \bar{M} can be computed. The average length intercepting one plant, L , can be determined by dividing the total transect length, T , by the number of interceptions as before. The transect can then be regarded as many sub-transects of length L , lying parallel to each other at intervals of \bar{M} to form a rectangle. The only problem remaining is to determine W , and W is arbitrarily chosen to make A the desired unit area. If the measurements are being made in feet and it is convenient to express the results as density per acre, then 43,560 is divided by L to yield the required W . Note again, that if such an area A were established, the enclosed plants must be capable of re-arrangement without rotation, so as to exactly stretch across any width W , if L is truly the length intercepting one plant per transect. This situation is obviously analogous to the hypothetical one outlined above, and density can be obtained by dividing W by \bar{M} . We have the following formulae: $A = LW$ and $D = W/\bar{M}$; substituting, we have $W = AN/T$ and $D = AN/T\bar{M}$.

\bar{M} , however, must be the average for the population, not merely for the intercepted plants. All other things being equal, a plant of width $M = 2$ has twice the probability of being intercepted as one of $M = \text{unity}$. To eliminate this size bias, the number of interceptions of each size must be divided by that size. If averaging is carried out using these corrected numbers, it becomes apparent that \bar{M} is equal to N divided by the sum of the reciprocals of the M measurements. Therefore the density formula can be simplified by substitution, becoming

$$D = \sum 1/M \times A/T.$$

EXPERIMENTAL VERIFICATION OF THE METHOD

Because the only measurements necessary are the M measurements, it was decided that a population map was unnecessary and that sampling could be conducted from a table. Table I shows the X co-ordinates for the centers and left and right margins of 80 plants: the Y co-ordinates are irrelevant. Also shown are M values and their reciprocals. The area sampled was assumed to be a square with an area of 10,000 square units. The co-ordinates for the centers and the M values were drawn from a random numbers table, the only restriction being

TABLE I. The X co-ordinates for the centers (C) and left and right margins (L and R) of the 80 plants, as well as the M values and their reciprocals are presented, ordered according to the occurrence of their centers.

	C	L	R	M	1/M
00.			02.35	4.7	.213
02.			04.45	4.9	.204
02.	00.40		03.60	3.2	.312
04.		01.30	06.70	5.4	.185
05.	02.25		07.75	5.5	.182
05.	01.70		08.30	6.6	.151
07.	04.45		09.55	5.1	.196
07.	03.75		09.25	6.5	.154
08.	05.05		10.95	5.9	.169
09.	07.30		10.70	3.4	.294
09.	05.45		12.55	7.1	.141
10.	08.85		11.15	2.3	.435
11.	06.20		15.80	9.6	.104
11.	07.90		14.10	6.2	.161
11.	06.95		15.05	8.1	.123
14.	10.65		17.35	6.7	.149
15.	12.60		17.40	4.8	.208
16.	11.95		20.05	8.1	.123
23.	19.25		26.75	7.5	.133
24.	20.60		27.40	6.8	.147
25.	22.80		27.20	4.4	.227
27.	25.80		28.20	2.4	.417
28.	24.35		31.65	7.3	.137
29.	24.35		33.65	9.8	.108
31.	26.90		35.10	8.2	.122
31.	26.60		35.40	8.8	.114
31.	28.35		33.65	5.3	.189
31.	26.25		35.75	9.5	.105
32.	29.35		34.65	5.3	.189
32.	30.35		33.65	3.3	.303
33.	28.80		37.20	8.4	.119
35.	32.80		37.20	4.4	.227
36.	34.70		37.30	2.6	.385
36.	34.15		37.85	3.7	.270
38.	36.70		39.30	2.6	.385
38.	35.50		40.50	5.0	.200
38.	34.85		41.15	6.3	.159
39.	37.50		40.50	3.0	.333
41.	37.45		44.55	7.1	.141
41.	39.65		42.35	2.7	.370
43.	38.55		47.45	8.9	.112
43.	38.65		47.35	8.7	.115
43.	40.90		45.10	4.2	.238
44.	42.10		45.90	3.8	.263
48.	46.25		49.75	2.5	.400
49.	45.85		52.15	6.3	.159
54.	51.50		56.50	5.0	.200
54.	52.60		55.40	2.8	.357
57.	55.75		58.25	2.5	.400
57.	55.10		61.90	9.8	.102
61.	56.65		65.35	8.7	.115
61.	58.50		63.50	5.0	.200
61.	58.50		63.50	5.0	.200
62.	59.85		64.15	4.3	.233
64.	61.05		66.95	5.9	.169
65.	63.95		66.05	2.1	.476
65.	62.25		67.75	5.5	.182
72.	69.05		74.95	5.9	.169
73.	70.55		75.45	4.9	.204
74.	72.45		75.55	3.1	.323
76.	71.60		80.40	8.8	.114
80.	78.85		81.15	2.3	.435
81.	77.10		84.90	7.8	.128
83.	78.30		87.70	9.4	.106
83.	79.35		86.65	7.3	.137
86.	83.05		88.95	5.9	.169
87.	84.55		89.45	4.9	.204
89.	84.05		93.95	9.9	.101
89.	84.25		93.75	9.5	.105
89.	87.90		90.10	2.2	.455
91.	88.85		93.15	4.3	.232

TABLE I. Continued

C	L	R	M	1/M
93.....	91.75	94.25	2.5	.400
93.....	91.75	94.25	2.5	.400
95.....	93.35	96.65	3.3	.303
96.....	93.05	98.95	5.9	.169
97.....	95.70	98.30	2.6	.385
97.....	92.35	9.3	.107
97.....	92.90	8.2	.122
97.....	94.95	99.55	5.1	.196
98.....	95.30	5.4	.185

TABLE II. The X co-ordinates of the 50 transects are given here in numerical order.

01	08	30	38	47	56	61	73	77	92
01	10	32	43	48	57	62	74	80	94
01	16	33	46	49	58	64	75	85	95
03	17	37	47	50	59	65	75	86	96
04	30	38	47	50	60	71	76	92	97

that plants with an *M* value under 0.2 units were rejected. Fifty X co-ordinates for transects, listed in Table II, were then drawn from a random numbers table and the 1/*M* value for every plant enclosing a transect co-ordinate within its margins was recorded. The data follow.

Area sampled (<i>A</i>)	10,000
Density parameter (<i>d</i>)	80
Total transect length (<i>T</i>)	5,000
Sum of the 1/ <i>M</i> values ($\Sigma 1/M$)	42.957
$D = 42.957 \times \frac{10,000}{5,000} = 85.914$	

DISCUSSION

The results are valid without regard to whether the plants are circular or systematically distorted, because *N*

in the unsimplified formula, $D = AN/T\bar{M}$, depends partly on \bar{M} for its value. To take a concrete example, if all plants are elongated in one direction by a strong prevailing wind, and the transect runs parallel to their greatest lengths, then *N* and \bar{M} both will be small. If the transect is run at right angles, *N* and \bar{M} will both be large. It can be seen that *N* and \bar{M} interact in such a way that the density estimate is unaffected. The only requirement is the usual one that the sample must be truly representative of the population. To this end, the stratified sampling pattern would probably be more valid than a single long transect.

The measurement employed by McIntyre is the longest whole chord parallel to the transect, although he gives two less sensitive techniques using only chord of interception data. All three of these formulae employ the correction factor \bar{C} , which is the mean value of the ratio of the *M* measurements to the longest chord measurements, giving equal weight to all angles of orientation. The value of this factor must be estimated by eye, although McIntyre suggests a value of 1.05 for most plant material. In the longest chord method, the sum of the reciprocals of the longest chords is multiplied by the desired unit-area and divided by the product of \bar{C} and the total transect length. Except for the two differences noted, McIntyre's method is precisely the same as the one presented here.

ACKNOWLEDGMENTS

I would like to express my thanks to Dr. Robert Burgess, North Dakota State University, for encouragement during the early phases of this problem, and to G. A. McIntyre, C.S.I.R.O., Canberra, Australia, for suggesting the use of $\Sigma 1/M$ in place of N/\bar{M} .

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MOVEMENT OF THE CRAWFISH *FAXONELLA CLYPEATA* IN A LINEAR MAZE¹

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Abstract. Dispersal of the crawfish *Faxonella clypeata* in a linear environment does not show a density-dependent relationship in populations of 1, 5, 10, 20, and 30 animals.

Crawfish without chelae moved approximately the same distance per time period as intact animals. Animals with antennae or eyestalks absent moved less than intact animals. The control of locomotion by a hormone originating in the eyestalk possibly explains why eyestalkless animals had very little movement. The means for the dispersal of intact male and female groups were not significantly different from each other.

The innate tendency toward dispersal may be found in some crawfish species demonstrating intra-specific aggressive behavior.

INTRODUCTION

A survey of the literature shows a difference of opinion concerning dispersal of animals in relation to density. In the crawfish *Cambarus allenii* and the crab

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Pachygrapsus crassipes, Bovbjerg (1959, 1960) found a direct relationship between initial density and rate of movement. Andrewartha and Birch (1954) proposed that dispersal is an innate tendency not necessarily related to density. Some investigators have proposed that the speed of locomotion and diurnal rhythm in locomotor activity are controlled by a hormone from the eyestalks, but con-

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