THE STATISTICAL ANALYSIS OF CHAPARRAL AND OTHER PLANT COMMUNITIES BY MEANS OF TRANSECT SAMPLES

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In many field investigations some method of sampling vegetation must be employed to procure data from which can be made computations of the abundance and importance of species. The method should be both accurate and easy to use. The methods generally used in the past have been lacking in one or the other of these characteristics.

The easiest and least accurate method of ascertaining the relative importance of the several species in a plant community is by ocular estimation, which is merely making the best guess possible. The quantitative relations among the species are sometimes expressed by assigning them to abundance classes described by such terms as: very rare, rare, infrequent, locally frequent, scarce, sparse, occasional, scattered, common, copious, locally abundant, moderately abundant, abundant, moderately dense, dense and dominant. When these terms are not standardized, the assigning of species to such classes is highly subjective and the method often lacks the exactness necessary for scientific analysis. There are various methods of determining the quantitative relations among the species of a community. Most of these are based on the examination of samples, located either at random or along definite lines through the area studied. The measurements of the vegetation in these samples are tabulated and abundance or other desired matters are calculated. The methods of sampling vegetation and of presenting the results have constituted serious problems ever since Pound and Clements ('98) proposed the quadrat as an accurate means of determining the abundance of species in plant associations.

There are several distinctly different concepts in quantitative relations. These are:

(1) Numerical abundance, in which all the specimens are counted, but the individual plants are not measured in any way. The importance of a given species may be expressed as its percentage of all individuals of all the species recorded; that is, "percentage of vegetation."

(2) Frequency index or percentage, a study of distribution in which the presence of the species is noted, but individual plants are neither measured nor counted. The importance of a given species is expressed as the percentage of samples in which it occurs, taken on the area investigated.

(3) Coverage extent, in which the area of ground covered by the crown, or other portion, of each individual plant is measured. The importance of a given species is assumed to be expressed by either the per cent of the total ground surface that it covers or as its percentage area in the total area covered by vegetation recorded.

(4) Volumes for each species.

(5) Dry weight and per cent of total dry weight for each species produced per unit of time.

REVIEW OF THE LITERATURE

Methods of making statistical analyses of vegetation have been discussed extensively and ably by a number of ecologists. A great deal of the discussion has centered around Raunkiaer's ('09, '18) frequency

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method, and attempts by various investigators to calculate abundance from formulae and other theoretical devices. The size, shape, and location of the sample plots have also received attention.

Among the early contributions to the subject were those of Arrhenius ('21, '22, '23) and Gleason ('20, '22, '25). Kenoyer ('27), in his study of Raunkiaer's work, included an excellent summary of the statistical methods used up to that year. Hanson and Ball ('28) applied the frequency method to grazing studies. Gleason ('29) showed that frequency percentages vary considerably with the size of the quadrat employed. Nichols ('30) emphasized the importance of quadrat and coverage data. Romell ('30) cautioned against comparing statistics based on different-sized sample plots and pointed out the advantage of areal or coverage measurements over frequency. Hanson and Love ('30) compared and discussed the merits of five methods of quadratting. Christidis ('31) recommended that sample plots be as long and narrow as possible to reduce the effect of heterogeneity.

In an extensive discussion of sociological concepts Cain ('32) commented on the terminology used in analyzing and describing vegetation and pointed out the error of considering species of high frequency as necessarily being dominant. Hanson ('34) compared several methods of analyzing the native prairie of North Dakota. McGinnies ('34) discussed both the theoretical aspects and field applications of quadrat sampling and frequency calculations in several types of vegetation in Arizona.

Blackman ('35) recommended the "percentage of absence" of species as a means of studying changes in density. Ashby ('35) criticized much of the work in statistical ecology as being based on unsatisfactory assumptions, such as that of complete random distribution in plant communities. Singh and Das ('39) studied the relation between frequency percentages and density in weed flora. Pechanec and Stewart ('40), in an investigation of the sagebrush range of Idaho, found that long narrow sample plots were generally somewhat more efficient than square ones of the same size, and concluded that in selecting sampling devices a balance must be struck between sampling accuracy and such practical considerations as the time and effort required.

Although numerous investigations involving quantitative analysis of vegetation have been carried out in herbaceous and forest communities, very few studies have been reported for scrub or brush communities. Nelson ('30) described a method of charting shrubby vegetation for planimeter measurements. Adamson ('31), in studying the brush cover of South Africa, found that samples located at random gave about the same results as those located in straight lines. Horton ('41) made statistical analyses of the Californian chaparral and concluded that the milacre plot is a suitable size sample for bringing out important ecological relationships in this type of vegetation, but calls attention to the great amount of time required to complete the field and office work.

Until recently practically no reports of quantitative analyses of vegetation based on transect sampling rather than on quadrats, have appeared in the literature. Bauer ('36, pp. 422–426), in an investigation of the Californian chaparral, gave a brief account of transect sampling in which the distance that each individual plant spread over the line was recorded and used as the basis for various calculations. Hasel ('41), in a study of reproduction in forests, used a method of linear measurement as a substitute for mapping. Canfield ('41) described the line interception method as applied to range studies.

Since transect sampling has been used so seldom in the past, it is apparent that the workers either assume that transect data are not valid or that they have overlooked its advantages. The writer (Bauer, '36), in attempting to make a quadrat study of the brush cover of the Santa Monica Mountains, encountered so many difficulties that he was forced to conclude that extensive quadratting in a dense thicket was impractical. As a result, the transect method was adopted and much more satisfactory results were obtained.

Although small two-dimensional sample plots can be located quickly in herbaceous vegetation by dropping a wire or iron frame on the ground, this is not true of vegetation made up largely of shrubs or trees. In scrub and forest communities a transect can be run and the desired data recorded in a small fraction of the time required to establish a quadrat and make corresponding records. This is especially true if direct measurements of the individual plants are to be made as a means of determining ground coverage from which the relative importance of the species can be computed. However, questions may be raised as to the representativeness and accuracy of transect data as compared with quadrat data. The chief purpose of this paper is to compare the efficiency of the transect and the quadrat methods of sampling vegetation, and also to compare several different methods of expressing a given set of measurements.

Laboratory Tests

In order to get information as to the relative accuracy of the transect and quadrat methods of sampling, and also as a means of comparing the accuracy of several methods of expressing data, a series of laboratory tests was carried out. In these, cardboard discs of various colors were spread out on a specially prepared board or table top of one square meter, in such a way as to simulate a plant community. Each color represented a species and each disc an individual plant. The discs were cut to definite sizes and the number used was such that the area covered and the percentage of the whole was known for each color. The sizes and proportions were intended to approximate roughly those found in the Californian chaparral.

Before the samples were taken the discs were thoroughly mixed and spread on the board by hand. No conscious effort was made to place any particular disc or color in any particular place. An attempt was made to distribute the discs over the surface with fair uniformity, by avoiding pile-ups and noticeably large bare spaces. The total area covered by all the discs was in every case the same as that of the board, namely 10,000 square centimeters. Since the discs were circular, there was some overlapping and there were some interstices among them. Each disc within the sample area was recorded completely, even though it might be partly covered by another disc. The bare spaces were not recorded.

After the discs were scattered over the board, the assemblage ("community") was sampled by means of four transects and four quadrats. The samples were located at random, but one transect and one quadrat were taken somewhere near each corner of the board. The transects were taken along the edge of a transparent 30 cm. celluloid ruler. The distance that each sampled disc extended along the transect line was measured and entered on a specially prepared form.

The quadrat samples were taken by means of a square (10 cm. on each side) marked on a transparent piece of celluloid. The area of each disc, or portion of a disc, inside the quadrat was recorded. In order to get complete coverage, all pieces were recorded, even though the center of the disc was outside the square. Where only a portion of the disc was inside the quadrat, its area was measured by matching with previously prepared pieces of known size.

After the eight samples (four transects and four quadrats) were posted, the discs were picked up, thoroughly mixed, and redistributed over the board. Two hundred assemblages ("communities") were sampled in each of the four tests made.

Test 1

In the first test all the discs were of the same size, each having an area of ten square centimeters. One hundred discs of each color were used, and each of the ten colors, therefore, constituted ten per cent of the entire assemblage.

Table I shows the results of the measurements made in the first test. The figures given are percentages of all the discs ("vegetation") recorded for each of the three concepts. "Coverage" is the complete coverage of the line or in the quadrat, being based on measurements of each individual disc. In the "numerical abundance" part of the table, the number of discs of each color was used as a basis for the percentage calculations, rather than the measurements of the individual discs.

TABLE I. *Percentages of colors ("species") in 200 assemblages ("communities") composed of dissc ("plants") which were all of the same size and in which each color was equally abundant*

Color	Actual per cent of all colors ("Vegetation")	Data based on measurements by the transect method		Data based on measurements by the quadrat method	
		Per cent as measured	Deviation	Per cent as measured	Deviation
Data based on coverage measurements					
Black	10.00	10.43	0.43	9.57	0.43
Brown	10.00	9.91	0.09	9.65	0.35
Blue	10.00	10.20	0.20	10.39	0.39
Violet	10.00	9.34	0.66	9.89	0.11
Indigo	10.00	9.92	0.08	10.15	0.15
Green	10.00	9.98	0.02	9.91	0.09
Yellow	10.00	9.67	0.33	10.24	0.24
Orange	10.00	10.42	0.42	9.94	0.06
Red	10.00	10.45	0.45	10.20	0.20
White	10.00	9.75	0.25	10.00	0.00
Average			0.293		0.202
Data based on numerical abundance					
Black	10.00	10.56	0.56	9.44	0.56
Brown	10.00	9.81	0.19	9.65	0.35
Blue	10.00	10.24	0.24	10.34	0.34
Violet	10.00	9.16	0.84	10.04	0.04
Indigo	10.00	10.08	0.08	10.37	0.37
Green	10.00	9.80	0.20	9.93	0.07
Yellow	10.00	9.86	0.14	10.10	0.10
Orange	10.00	10.46	0.46	9.79	0.21
Red	10.00	10.34	0.34	10.40	0.40
White	10.00	9.77	0.23	9.93	0.07
Average			0.328		0.251
Data based on frequency					
Black	10.00	10.44	0.44	10.07	0.07
Brown	10.00	10.18	0.18	9.92	0.08
Blue	10.00	10.02	0.02	9.94	0.06
Violet	10.00	9.55	0.45	9.79	0.21
Indigo	10.00	9.76	0.24	10.07	0.07
Green	10.00	9.91	0.09	9.95	0.05
Yellow	10.00	9.63	0.37	10.01	0.01
Orange	10.00	10.32	0.32	9.94	0.06
Red	10.00	10.27	0.27	10.25	0.25
White	10.00	9.88	0.12	10.01	0.01
Average			0.255		0.087

In the "frequency" part of the table, neither measurement nor counting of the individuals was used. The percentages given are based on the frequency of occurrence of a given color in all the samples taken. In tabulating frequency, several discs of a certain color are not weighted any more heavily than a single one of the same color that touches some part of the 30 cm. transect or is found inside the 10 cm. quadrat.

The most noticeable thing about table I is the close agreement between the two methods of sampling and also between the three methods of expressing the results. The percentages based on quadrat samples, especially where based on frequency, are slightly more accurate than those based on transect samples. In the case of coverage, the average amount of deviation of the composition percentages as measured, from the actual percentages is 0.29 for the transects and 0.20 for the quadrats.

The slightly better showing of the quadrats is probably due to the fact that the set-up favored the quadrats. The transect used was rather short, being only three times longer than the side of the quadrat. In order to be equivalent, two sampling devices should yield about the same number of statistical items. In this test the quadrats included about 38 per cent more items than did the transects. It should also be remembered that in a natural community of mixed species not all of the plants will have the same size body, and the species will not be of equal abundance.

Test 2

In the second test the procedure was the same as in the first except that the colors were not equally abundant. The black and the brown each constituted 25 per cent of the entire assemblage, but the red and the white only 1.5 per cent. The total surface covered by the ten colors was the same as in the first test. The purpose was to find out which method of sampling would give better results in the case of the colors ("species") present in small percentages.

Data for the second test are given in table II. The average amount of deviation under the conditions of this test is considerably greater than in the first test, but there is still no appreciable difference between the transect and the quadrat methods of taking the samples. Based on coverage, the average amount of deviation for the transects is 1.006 and that for the quadrats is 0.983. When the percentages are based on numerical abundance the results are practically the same as when coverage is used.

Since all the discs used in this test were of the same size, the percentages in the samples should be directly proportional to the numbers used, and the mathematical expectancy would be, therefore, the same as the percentage composition of the entire assemblage ("community"), in the case of coverage and numerical abundance. In the case of frequency, however, this is not true because of the element of probability. The mathematical expectancies were calculated from the following formulae: [2]

$$\text{for the transects, } F = 1 - (1 - P)^N$$

$$\text{for the quadrats, } F = 1 - (1 - P')^N.$$

In these formulae, "F" is the frequency expected, "N" is the number of discs of a given color used, "P" is the probability of a disc being included in a transect sample, and "P'" is the probability of a disc being included in a quadrat sample. The probability is calculated from the formulae,

$$\text{for the transects, } P = \frac{2ar + \pi r^2}{A^2}$$

$$\text{for the quadrats, } P' = \frac{b^2 + 4br + \pi r^2}{A^2}.$$

In these formulae, "a" is the length of the transect line, "r" is the radius of the

[2] The formulae used for calculating the mathematical expectancies were provided by Dr. Paul G. Hoel, Assistant Professor of Mathematics, University of California at Los Angeles.

TABLE II. *Percentages of colors ("species") in 200 assemblages composed of discs of uniform size but in which the colors were of different abundance*

Color	Number of discs	Actual per cent of all colors ("Vegetation")	Data based on measurements by the transect method			Data based on measurements by the quadrat method		
			Mathematical expectancy	Per cent as measured	Deviation	Mathematical expectancy	Per cent as measured	Deviation
Data based on coverage measurements								
Black	250	25.00	25.00	22.61	2.39	25.00	22.34	2.66
Brown	250	25.00	25.00	22.34	2.66	25.00	22.99	2.01
Blue	125	12.50	12.50	13.50	1.00	12.50	12.94	0.44
Violet	125	12.50	12.50	12.82	0.32	12.50	12.26	0.24
Indigo	75	7.50	7.50	8.60	1.10	7.50	8.44	0.94
Green	75	7.50	7.50	7.97	0.47	7.50	8.21	0.71
Yellow	35	3.50	3.50	3.93	0.43	3.50	4.19	0.69
Orange	35	3.50	3.50	3.69	0.19	3.50	3.93	0.43
Red	15	1.50	1.50	2.52	1.02	1.50	2.45	0.95
White	15	1.50	1.50	1.98	0.48	1.50	2.26	0.76
Average					1.006			0.983
Data based on numerical abundance								
Black	250	25.00	25.00	22.83	2.17	25.00	22.69	2.31
Brown	250	25.00	25.00	22.28	2.72	25.00	23.23	1.77
Blue	125	12.50	12.50	13.20	0.70	12.00	12.79	0.29
Violet	125	12.50	12.50	12.86	0.36	12.50	12.00	0.50
Indigo	75	7.50	7.50	8.70	1.20	7.50	8.36	0.86
Green	75	7.50	7.50	7.98	0.48	7.50	8.23	0.73
Yellow	35	3.50	3.50	5.97	0.47	3.50	4.22	0.72
Orange	35	3.50	3.50	3.65	0.15	3.50	3.96	0.46
Red	15	1.50	1.50	2.42	0.92	1.50	2.29	0.79
White	15	1.50	1.50	2.10	0.60	1.50	2.27	0.77
Average					0.977			0.920
Data based on frequency								
Black	250	25.00	16.89	16.59	0.30	14.78	15.08	0.30
Brown	250	25.00	16.89	16.33	0.56	14.78	14.98	0.20
Blue	125	12.50	13.74	13.55	0.19	13.42	13.42	0.00
Violet	125	12.50	13.74	13.11	0.63	13.42	12.35	1.07
Indigo	75	7.50	10.46	10.63	0.17	11.15	10.80	0.35
Green	75	7.50	10.46	10.14	0.32	11.15	10.84	0.31
Yellow	35	3.50	6.02	6.18	0.16	7.06	7.11	0.05
Orange	35	3.50	6.02	5.48	0.54	7.06	6.62	0.44
Red	15	1.50	2.89	4.17	1.28	3.58	4.35	0.77
White	15	1.50	2.89	3.57	0.68	3.58	4.39	0.81
Average					0.483			0.430

disc used, "b" is the side of the quadrat and "A" is the side of the square area over which the entire assemblage is distributed.

The formula for the quadrats is similar to the one used by Gleason ('20) for calculating the frequency index. The formula used here, however, recognizes the fact that the effective quadrat used had rounded corners. Since all discs within the quadrat were recorded, even though their centers were outside, the effective size of quadrat actually used was 10 cm. plus the diameter of the disc, as shown in figure 1.

The formula for computing the mathe-

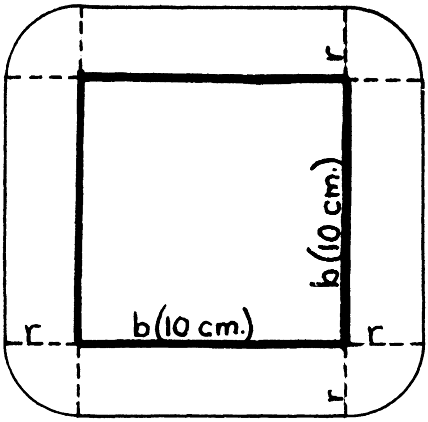

FIG. 1. Diagram showing the shape and other details of the effective quadrat used in sampling simulated plant communities, and from which the probabilities were calculated. Formulae and explanations in the text.

matical expectancies in the case of the transect is based on the fact that the probability of a certain disc touching the transect line is the same as the probability of the center of that disc falling within an area as long as the line, having a width of one diameter, and having a half disc added at each end. Such an area is illustrated in figure 2.

When the percentages based on frequency data are compared with the mathematical expectancies calculated according to the formulae given, a remarkable agreement is noted in the case of both the transect and the quadrat sampling, the average deviations being 0.483 and 0.430 respectively.

In the case of both methods of sampling and of each method of expressing the results, the percentages calculated from the measurements are somewhat too low for the colors constituting high percentages of the whole, and somewhat too high for the colors constituting low percentages of the whole.

Test 3

In the third test the discs were not all of the same size, but the area covered by each color was the same, namely 1,000 sq. cm., and each color, therefore, constituted 10 per cent of the total surface covered. The assemblage consisted of 10 black and 10 brown discs, each having an area of 100 sq. cm.; 13⅓ blue and 13⅓ violet discs, each having an area of 75 sq. cm.; 20 indigo and 20 green discs, each having an area of 50 sq. cm.; 40 yellow and 40 orange discs, each having an area of 25 sq. cm.; and 100 red and 100 white discs, each having an area of 10 sq. cm. The purpose of this test was to see if either of the two sampling devices had greater efficiency than the other in sampling colors ("species") which consisted of a comparatively few large individuals rather than of numerous small ones. This arrangement, of course, resembles a natural community of mixed species more closely than was the case in either of the previous tests.

Data for the third test are given in table III. The mathematical expectancies in the case of coverage data is the same as the percentage composition of the entire assemblage. The expectancies for the frequency data were calculated from the formulae given on page forty-nine. For the numerical abundance data, the expectancies for the transect samples were calculated from the formula *NP*, and those for the quadrat samples from the

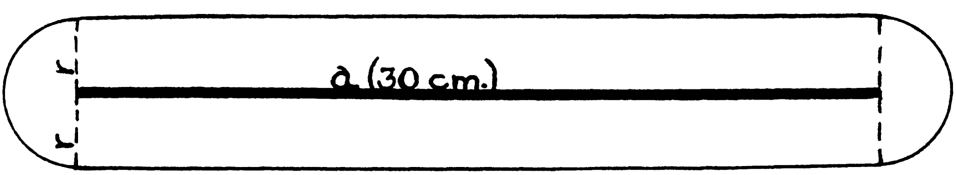

FIG. 2. Diagram showing the shape and other details of the area used in calculating the probability of a disc touching the transect used in sampling assemblages of colored discs. Formulae and explanations in the text.

TABLE III. *Percentages of colors ("species") in 200 assemblages composed of discs ("plants") of various sizes but in which each color covered the same area*

Color	Actual per cent of all colors ("Vegetation")	Data based on measurements by the transect method			Data based on measurements by the quadrat method		
		Mathematical expectancy	Per cent as measured	Deviation	Mathematical expectancy	Per cent as measured	Deviation
Data based on coverage measurements							
Black	10.00	10.00	11.48	1.48	10.00	8.05	1.95
Brown	10.00	10.00	10.61	0.61	10.00	8.80	1.20
Blue	10.00	10.00	8.63	1.37	10.00	8.08	1.92
Violet	10.00	10.00	9.90	0.10	10.00	9.88	0.12
Indigo	10.00	10.00	10.50	0.50	10.00	8.86	1.14
Green	10.00	10.00	9.51	0.49	10.00	9.47	0.53
Yellow	10.00	10.00	9.10	0.90	10.00	11.86	1.86
Orange	10.00	10.00	10.15	0.15	10.00	11.31	1.31
Red	10.00	10.00	9.90	0.10	10.00	12.00	2.00
White	10.00	10.00	10.09	0.09	10.00	11.65	1.65
Average				0.579			1.368
Data based on numerical abundance							
Black	10.00	6.35	7.23	0.88	4.94	4.69	0.25
Brown	10.00	6.35	6.75	0.40	4.94	4.95	0.01
Blue	10.00	7.10	6.50	0.60	5.73	4.62	1.11
Violet	10.00	7.10	7.17	0.07	5.73	5.63	0.10
Indigo	10.00	8.38	8.32	0.06	7.20	6.65	0.55
Green	10.00	8.38	7.90	0.48	7.20	6.95	0.25
Yellow	10.00	11.25	10.93	0.32	11.06	11.00	0.06
Orange	10.00	11.25	11.54	0.29	11.06	11.50	0.44
Red	10.00	16.93	16.54	0.39	21.07	21.58	0.51
White	10.00	16.93	17.08	0.15	21.07	22.48	1.41
Average				0.364			0.469
Data based on frequency							
Black	10.00	7.43	8.45	1.02	6.60	6.28	0.32
Brown	10.00	7.43	7.89	0.46	6.60	6.77	0.17
Blue	10.00	8.07	7.25	0.82	7.38	6.23	1.15
Violet	10.00	8.07	8.31	0.24	7.38	7.48	0.10
Indigo	10.00	9.13	9.60	0.47	8.72	8.20	0.52
Green	10.00	9.13	8.83	0.30	8.72	8.45	0.27
Yellow	10.00	11.16	10.59	0.57	11.57	11.99	0.42
Orange	10.00	11.16	11.29	0.13	11.57	12.06	0.49
Red	10.00	14.21	13.87	0.34	15.70	16.47	0.77
White	10.00	14.21	13.86	0.35	15.70	16.00	0.30
Average				0.470			0.451

formula NP'. In these formulae, "N" is the number of circles used, "P" is the probability for the transects and "P'" the probability for the quadrats, these probabilities being calculated from the formulae previously given.

Inspection of the table shows that when the data are based on frequency, the two sampling devices are about equally accurate, but when coverage or numerical abundance was used the transects were more accurate than the quadrats. The advantage is especially marked in the case of the coverage data, the average deviation for the transects being 0.579 and that for the quadrats 1.368. As sampled by transects and expressed as coverage, the percentages show about the same deviation for all colors. However, as sampled by quadrats, there is a marked tendency for the percentages of those colors present as a few large discs to be too low and for those of the colors present as numerous small discs to be too high. This may be due to the fact that the transect has greater linear extent and reaches into more of the entire area being sampled.

Test 4

In the fourth test the colors varied as to the amount of surface covered, and each color consisted of three different-sized discs. There was also variation among the colors as to the average size of the three discs. Details of the composition of this assemblage are given in table IV. The plan was to simulate as nearly as possible the conditions in a natural community of mixed species. In such a community the species not only vary as to the amount of ground surface covered but also as to the characteristic sizes of the plants.

Results of the fourth test are given in table V. The mathematical expectancies for the coverage data are the same as the percentage composition of the entire assemblage. The expectancies for the numerical abundance data were computed from the following formulae:

for the transects, $N_1P_1 + N_2P_2 + N_3P_3$

for the quadrats, $N_1P'_1 + N_2P'_2 + N_3P'_3$.

The expectancies for the frequency data were computed from the following formulae:

for the transects, $F = 1 - (1 - P_1)^{N_1} \times (1 - P_2)^{N_2} \times (1 - P_3)^{N_3}$

for the quadrats, $F = 1 - (1 - P'_1)^{N_1} \times (1 - P'_2)^{N_2} \times (1 - P'_3)^{N_3}$.

In the above formulae the subscripts refer to each of the three sizes of discs of which each color is composed in this test. The symbols are the same as in the formulae previously given.

TABLE IV. *Numbers and areas of discs used in Test IV, and the percentages of total surface covered*

Color	Number of discs used	Area of disc. Sq. cm.	Area covered	Percentage of total coverage
Black	10	100	1000	24
	10	80	800	
	10	60	600	
Brown	10	100	1000	24
	10	80	800	
	10	60	600	
Blue	7	80	560	12
	6	60	360	
	7	40	280	
Violet	7	80	560	12
	6	60	360	
	7	40	280	
Indigo	7	60	420	8
	6	40	240	
	7	20	140	
Green	7	60	420	8
	6	40	240	
	7	20	140	
Yellow	6	40	240	4
	5	20	100	
	6	10	60	
Orange	6	40	240	4
	5	20	100	
	6	10	60	
Red	6	20	120	2
	5	10	50	
	6	5	30	
White	6	20	120	2
	5	10	50	
	6	5	30	

Examination of table V shows that the results of the fourth test are about the same in principle as those obtained in the third test. Transect and quadrat sampling are about equally accurate when the percentages are based on frequency and on numerical abundance. However, the transect has a distinct advantage when coverage data are considered, the average deviation being 0.719 for the transect and 1.181 for the quadrat. The tendency of both methods to give percentages too low for the more abundant colors and too high for the less abundant one is apparent.

In tables I, II, III and V, the data,

TABLE V. *Percentages of colors ("species") in 200 assemblages of discs ("plants") in which the colors varied as to the amount of surface covered, and in which each color consisted of discs of three different sizes*

Color	Actual per cent of all colors ("Vegetation")	Data based on measurements made by the transect method			Data based on measurements made by the quadrat method		
		Mathematical expectancy	Per cent as measured	Deviation	Mathematical expectancy	Per cent as measured	Deviation
Data based on coverage measurements							
Black	24.00	24.00	22.61	1.39	24.00	21.09	2.91
Brown	24.00	24.00	22.31	1.69	24.00	21.56	2.44
Blue	12.00	12.00	12.12	0.12	12.00	12.41	0.41
Violet	12.00	12.00	11.48	0.52	12.00	11.44	0.56
Indigo	8.00	8.00	9.14	1.14	8.00	8.94	0.94
Green	8.00	8.00	8.47	0.47	8.00	9.39	1.39
Yellow	4.00	4.00	4.33	0.33	4.00	5.23	1.23
Orange	4.00	4.00	4.63	0.63	4.00	4.94	0.94
Red	2.00	2.00	2.37	0.37	2.00	2.55	0.55
White	2.00	2.00	2.53	0.53	2.00	2.44	0.44
Average				0.719			1.181
Data based on numerical abundance							
Black	24.00	20.44	18.90	1.54	18.59	16.95	1.64
Brown	24.00	20.44	18.78	1.66	18.59	17.52	1.07
Blue	12.00	11.42	11.41	0.01	10.84	10.76	0.08
Violet	12.00	11.42	11.03	0.39	10.84	10.01	0.83
Indigo	8.00	8.90	9.92	1.02	9.09	9.64	0.55
Green	8.00	8.90	9.49	0.59	9.09	9.50	0.41
Yellow	4.00	5.50	5.70	0.20	6.33	7.27	0.94
Orange	4.00	5.50	6.01	0.51	6.33	6.63	0.30
Red	2.00	3.75	4.11	0.36	5.15	6.08	0.93
White	2.00	3.75	4.65	0.90	5.15	5.65	0.50
Average				0.718			0.725
Data based on frequency							
Black	24.00	17.04	16.68	0.36	15.56	15.18	0.38
Brown	24.00	17.04	16.23	0.81	15.56	15.20	0.36
Blue	12.00	11.82	11.73	0.09	11.13	11.46	0.33
Violet	12.00	11.82	11.39	0.43	11.13	10.58	0.55
Indigo	8.00	9.80	10.12	0.32	9.78	9.75	0.03
Green	8.00	9.80	10.51	0.71	9.78	9.75	0.03
Yellow	4.00	6.62	6.55	0.07	7.35	7.83	0.48
Orange	4.00	6.62	6.75	0.13	7.35	7.22	0.13
Red	2.00	4.71	4.84	0.13	6.18	6.69	0.51
White	2.00	4.71	5.20	0.49	6.18	6.32	0.14
Average				0.354			0.294

regardless of whether the measurements were recorded as numerical abundance, frequency or coverage, were given as "per cent of vegetation," in order to make valid comparisons. In the case of coverage measurements, the data might better be presented as the actual area covered. If the two-dimensional quadrats truly represent the entire community, the percentage of coverage within the quadrats is also the percentage of coverage in the larger area. In the case of the transect, however, it might be questioned whether or not the percentage of the sample line cov-

TABLE VI. *Relation of the percentage of the line covered in the transect samples and the percentage of the surface area covered in the quadrat samples to the true percentage of coverage in the large assemblage ("community")*

Color	True per cent of coverage in larger assemblage	Transect sampling		Quadrat sampling	
		Per cent of line covered	Deviation	Per cent of area covered	Deviation
Discs of uniform size; colors equally abundant					
Black	10.00	10.76	0.76	9.74	0.26
Brown	10.00	10.22	0.22	9.82	0.18
Blue	10.00	10.52	0.52	10.57	0.57
Violet	10.00	9.64	0.36	10.07	0.07
Indigo	10.00	10.23	0.23	10.34	0.34
Green	10.00	10.30	0.30	10.09	0.09
Yellow	10.00	9.97	0.03	10.43	0.43
Orange	10.00	10.75	0.75	10.12	0.12
Red	10.00	10.78	0.78	10.39	0.39
White	10.00	9.95	0.05	10.17	0.17
Average			0.40		0.26
Discs of uniform size; colors not equally abundant					
Black	25.00	19.89	5.11	19.43	5.57
Brown	25.00	19.66	5.34	19.98	5.02
Blue	12.50	11.88	0.62	11.25	1.25
Violet	12.50	11.28	1.22	10.64	1.86
Indigo	7.50	7.56	0.06	7.32	0.18
Green	7.50	7.01	0.49	7.14	0.36
Yellow	3.50	3.46	0.04	3.64	0.14
Orange	3.50	3.24	0.26	3.41	0.09
Red	1.50	2.22	0.72	2.13	0.63
White	1.50	1.74	0.24	1.96	0.46
Average			1.41		1.55
Discs of various sizes; each color covering same area					
Black	10.00	11.43	1.43	7.82	2.18
Brown	10.00	10.57	0.57	8.55	1.45
Blue	10.00	8.59	1.41	7.85	2.15
Violet	10.00	9.87	0.13	9.60	0.40
Indigo	10.00	10.42	0.42	8.67	1.33
Green	10.00	9.47	0.53	9.19	0.81
Yellow	10.00	9.10	0.90	11.52	1.52
Orange	10.00	10.12	0.12	10.99	0.99
Red	10.00	9.86	0.14	11.65	1.65
White	10.00	10.10	0.10	11.31	1.31
Average			0.57		1.37
Discs of various sizes; colors varying as to area covered					
Black	24.00	23.66	0.34	21.08	2.92
Brown	24.00	23.34	0.66	21.55	2.45
Blue	12.00	12.68	0.68	12.40	0.40
Violet	12.00	12.00	0.00	11.43	0.57
Indigo	8.00	9.56	1.56	8.94	0.94
Green	8.00	8.86	0.86	9.38	1.38
Yellow	4.00	4.52	0.52	5.23	1.23
Orange	4.00	4.84	0.84	4.94	0.94
Red	2.00	2.48	0.48	2.55	0.55
White	2.00	2.65	0.65	2.44	0.44
Average			0.659		1.182

ered is also the percentage of the surface area covered in the larger area.

Table VI is a comparison of the true percentage of the surface covered by the colored discs with the percentage of the line covered in the case of the transects and the percentage of the area covered in the case of the quadrats. It is apparent that the transect samples and the quadrat samples indicate the actual percentage of coverage with about equal accuracy in the case of those assemblages composed of individuals of uniform size (a situation rarely found in natural vegetation). It is rather surprising to note that in the assemblages composed of individuals of various sizes (the usual condition in natural plant communities) the transects indicate coverage in the larger area with considerably more accuracy than quadrats. In the assemblage that most nearly resembles a natural community, the average deviation for the transects was 0.659 and that for the quadrats 1.182.

Field Test

The information derived from the laboratory tests on simulated plant communities, described in the preceding pages, may have some practical applications in field studies involving the determination of the composition of the vegetation or other characteristics of plant communities. The transect method of sampling appears to have some definite advantages over quadrat sampling in certain types of vegetation, such as scrub or forest, where the individual plants are large enough and sufficiently well-defined to be measured quickly and accurately. Data based on transects, which involve measuring the plants in one dimension only, can be obtained in a small fraction of the time required to establish and make chart quadrats. Moreover, when coverage of the ground is considered or is taken as a basis for calculating percentage composition, data based on transect sampling appear to be more accurate, especially in mixed communities where individuals vary considerably as to size.

In order to test the transect method of sampling vegetation under field conditions, it was tried out on certain plots in the San Dimas Experimental Forest of the California Forest and Range Experiment Station, located near Glendora, California. At this forest, extensive studies of the relations between chaparral vegetation and moisture conditions are being made. The experimental work being done here is described by Kraebel and Sinclair ('40). The area used to make the test was a set of nine "Run-off and Erosion Plots" located on a northeasterly exposure with a slope of about 20 to 25 per cent. The chaparral vegetation here is tall and the stand so dense that much of it can be traversed only on hands and knees. Each plot is 10 ft. wide by 125 ft. long.

This area was selected because intensive quadrat studies of its floristic composition have been carried on for some years, and its percentage composition of species is probably known with more exactness than that for any other available area. In making the study the Forest Service has charted the entire surface of the nine plots graphically and to scale. Almost annually since 1935 this area has been carefully and completely measured. To do this requires, for each charting, about twenty man-days or 160 hours of time. Observations of herbage and litter are made as well as observations on the shrubby cover.

In measuring this area by the transect sample method, a single thirty-meter transect was run through each of the nine plots. A steel tape was used. The extent of crown projection along the line from either above or below, was measured and recorded in a specially prepared form. The sampling device used simulated a vertical plane transect rather than a line transect.

A summary of the data obtained by the two methods is given in Table VII. The figures given are percentages of composition, and are based on coverage measurements. There is fair agreement between the four-year averages of the two methods of measuring. The percentages of most

TABLE VII. *Percentage composition of species in the vegetation of nine run-off plots of the San Dimas Experimental Forest. Percentages are based on coverage*

Plant species	Measurements made in				4 year average
	1936	1938	1939	1941	
Data obtained from forest service quadrats					
Adenostoma fasciculatum	0.52	0.84	0.74	0.81	0.73
Arctostaphylos glauca	1.28	1.18	0.93	0.99	1.09
Ceanothus crassifolius	25.46	26.08	21.24	21.46	23.61
Ceanothus oliganthus	10.00	10.03	10.89	10.88	10.44
Cercocarpus betuloides	12.58	12.76	14.27	14.37	13.45
Photinia arbutifolia	2.22	2.37	2.80	3.38	2.67
Prunus ilicifolia	0.74	1.17	1.38	0.89	1.06
Quercus dumosa	46.58	45.16	47.30	46.70	46.51
Rhamnus crocea var. *ilicifolia*	0.34	0.27	0.38	0.32	0.33
Rhus ovata	—	0.01	0.04	0.14	0.03
Data obtained from transect samples					
Adenostoma fasciculatum	0.74	0.52	1.06	0.65	0.76
Arctostaphylos glauca	2.82	4.43	2.43	1.00	2.65
Ceanothus crassifolius	23.62	24.86	23.81	20.85	24.03
Ceanothus oliganthus	12.40	9.63	8.00	7.10	9.34
Cercocarpus betuloides	9.96	9.39	7.80	18.97	11.32
Photinia arbutifolia	2.20	2.11	2.85	2.98	2.58
Prunus ilicifolia	0.74	1.19	0.98	1.00	1.04
Quercus dumosa	43.14	46.85	52.28	46.64	47.48
Rhamnus crocea var. *ilicifolia*	0.82	—	—	0.71	0.20
Rhus ovata	0.96	0.36	0.72	0.14	0.56

of the species are surprisingly alike. In the case of *Arctostaphylos glauca* and *Cercocarpus betuloides* (all plant names according to Jepson, '25) the difference is more noticeable, but still the percentages are close enough to have considerable value.

In view of the short time required to take the transect samples, the similarity in the results of the two methods of measuring is remarkable. Only about three man-hours were required for the transects, whereas about 160 man-hours were spent in quadratting the area. It is probable that a few more hours spent in taking additional transects would yield practically the same results as charting the entire ground surface. It should be noted that in this field test, transect samples are not being compared with quadrat *samples* but with a 100 per cent charting of the entire area. Such complete charting is an accurate method but is not practical on a large area. It can only be used on small areas and when plenty of help is available. For most field investigations, a sampling method must be employed.

It should be remembered that the chaparral plots in which the field test was made was a particularly difficult sample of vegetation in which to work. The thicket was so dense that it could not be easily traversed, and, because of the overlapping branches, the limitations of the individual plants were often not clear. Moreover, the species were not uniformly distributed, some of them having a tendency to occur in patches in certain parts of the area. In spite of these handicaps fairly good results were obtained with a comparatively few transect samples which required only a few hours to take. With a more open type of vegetation, or a somewhat larger number of transects, still more accurate results would be expected.

Discussion

A study of the results of the laboratory tests shows that percentages based on transect sampling compare fairly well with percentages based on quadrat sampling in all cases, and that in some instances the transects gave decidedly more accurate results than the quadrats. Quadrat sampling appears to have a slight advantage in the assemblages composed of individuals of uniform size (a condition not generally found in nature) and in all cases where the percentages are based on frequency. In those assemblages composed of individuals of various sizes (the usual condition in nature) transect sampling appears to have a slight advantage when the percentages are based on numerical abundance, and a very decided advantage when they are based on coverage.

The advantages of the transect method may be even more pronounced than is indicated, in view of the fact that the experimental set-up used appears to favor the quadrat method. In order to make the fairest comparisons, the two sampling devices should yield about the same number of items. The thirty centimeter transect used did not include as many plants as the quadrat. In Tests 1 and 2, in which the assemblages consisted of discs of uniform size, about 38 per cent more entries were made in the quadrat record than in the transect record. In Tests 3 and 4, in which the discs were of various sizes including a number of comparatively large ones, over 12 per cent more items were entered in the quadrat than in the transect record. In spite of this advantage, the quadrats did not give markedly better results at any point, and in some cases, as noted above, were decidedly less accurate than the transects.

Numerical abundance data do not take into account the fact that plant bodies vary as to size. In counting, a small plant is weighted just as heavily as a large one, although it obviously produces less vegetation than a large one. This is an important matter in mixed communities where plants vary considerably in size. A species characterized by large individuals has greater importance in an association than a species composed of small plants, even though both species may have the same numerical abundance.

Frequency index data are subject to misleading interpretations, such as assuming that species of high frequency are necessarily "dominant" (Cain, '32). It has been shown (Gleason, '29) (Kenoyer, '27) that when the frequencies are grouped in the five frequency classes (A, B, C, D, & E) as is often done, the resulting ratios depend in large measure on the size of the quadrat sample used. In order to demonstrate Raunkiaer's law, different-sized sample plots must be used for different associations. For a given association quite different results are obtained when the size of the sample plot is varied. This brings into frequency index data an element of uncertainty that is undesirable in the quantitative analysis and comparison of different associations. Comparisons of vegetation cannot be made where different-sized quadrats have been used (Romell, '30). Frequency index tabulations are, however, useful to show uniformity, or lack of uniformity, in the distribution of species—that is, the degree of homogeneity of an association.

Coverage data have some distinct advantages. They provide a sound basis from which the percentage composition of the vegetation can be calculated, because they take into account the fact that plants vary as to size. In addition, coverage can be expressed as the actual amount of the ground surface covered, an important ecological character. It is coverage rather than numbers of plants or frequency of occurrence or other quantitative concepts used in the analysis of vegetation that determines dominance and gives character to a community. Because of these things coverage data may be thought of as more valuable and significant than other data intended to express the quantitative relations among species.

The time and labor involved in recording coverage data in the past have tended to discourage its extensive use. When quadrats are used as a basis for such computations, the individual plants are sometimes charted to scale and, later, the area of each measured with a planimeter (Hanson and Love, '30). Even when the areas within the quadrats are estimated instead of actually measured, much time is required and it may be doubted whether the results justify the labor.

The transect method of sampling vegetation, as described herein, offers a real saving of time and trouble in obtaining data as to coverage or other ecological relations with no loss of accuracy whatever. Indeed, the laboratory tests carried out indicate that, in mixed communities, transect sampling gave decidedly more accurate percentages of coverage than quadrat sampling. It is not clear why this is true but it is probably due to the fact that the transect has greater linear extent than the quadrat and reaches into more of the entire area being sampled.

The transect is not only suitable for obtaining data as to coverage, numerical abundance and frequency, as discussed above, but can be adapted to show other structural characteristics of vegetation. By recording appropriate units or items in the field record, it is probable that such characters as density, openness, luxuriance and volume can be ascertained with considerable accuracy. Since transects can be recorded in a small fraction of the time required to make the corresponding records from quadrats, investigators should give careful consideration to the possibilities of this method of sampling.

Summary

A series of laboratory tests involving measurements of simulated plant communities of known composition was conducted for the purpose of comparing the relative efficiency of the transect and the quadrat methods of sampling vegetation for statistical analysis. Comparisons were also made between three different concepts of quantitative relations, namely, (1) coverage, (2) numerical abundance and (3) frequency, or percentage of occurrence in the samples taken.

It was found that in communities in which the individuals were all of the same size (an unnatural condition) the transect and the quadrat methods of sampling were of about equal accuracy. Transect sampling, however, has the advantage of requiring much less time. In communities in which the individuals were of various sizes (the usual situation in nature) the transects gave decidedly more accurate results when the data were based on coverage measurements. This was probably due to the greater linear extent of the transects.

Comparisons of data obtained from the laboratory tests showed that, in the case of assemblages composed of individuals of various sizes, the per cent of the line covered in the transect samples was a considerably more accurate indication of the true areal coverage in the entire assemblage than was the per cent of the area covered within the quadrat samples.

A field test of transect sampling was made in the Californian chaparral, the main watershed cover in southern California. This shrubby thicket was so dense that much of it could be traversed only on hands and knees. The results, considering the comparatively small amount of time involved, compared very favorably with the results of a chart quadrat survey which covered the entire area studied and which required a great deal of time to make.

It is probable that transect sampling deserves a much wider use than has been made of it in the past. It appears to be well suited for use in scrub or other communities where the extent of the individual plants can be clearly observed. It is likely that most of the relations that can be determined from quadrat samples can also be determined from transect samples by making the proper adaptations, without loss of accuracy but with a very considerable saving of time.

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