

ACCURACY OF QUADRAT SAMPLING IN STUDYING FOREST REPRODUCTION ON CUT-OVER AREAS¹

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PURPOSE

The quadrat method, first introduced into ecological studies by Pound and Clements in 1898, has been adopted by both foresters and ecologists as one of the most accurate means of studying the occurrence, distribution, and development of vegetation (Clements, '05; Weaver, '18). This method is unquestionably more precise than the descriptive method which it superseded. Nevertheless, the results obtained are subject to certain types of experimental error in common with all methods of sampling in which it is necessary to picture conditions over large areas from representative fractions. Despite its long and wide-spread use, few investigators have seen fit to check the accuracy of the quadrat system, and our knowledge on this subject, particularly in the field of silvical investigations, is extremely limited. It is the purpose of this paper to discuss the accuracy of quadrat sampling as applied to the study of forest reproduction on cut-over areas, and to describe methods by which this accuracy can be measured.

THE DATA USED

The data here presented were gathered in a study of old cuttings in the western white pine forests of northern Idaho. In this study, reproduction counts were obtained on mil-acre quadrats (squares 6.6 feet on a side) laid out at intervals along parallel strips running at right angles to the main topographic features. The usual procedure was to lay out quadrats at one half to one-chain intervals (that is at 33 to 66 feet intervals) and to space adjacent strips 2.5, 5 or 10 chains apart. Two important averages obtained from these data were: (1) the percentage of area stocked, a value commonly termed the frequency index or F. I. (Gleason, '20), and (2) the average number of seedlings per acre. These figures are essential for weighing the merits of various methods of cutting in regard to obtaining satisfactory reproduction. They are based, in most reproduction studies, on an extremely small sample; in this instance on a sample of from .1 to .8 per cent of the total area; and it is obviously desirable to check their accuracy.

¹ Presented at the Annual Meeting of the Northwest Scientific Association, Spokane, Wash., December 28, 1928.

FREQUENCY INDEX IN OCCURRENCE OF SEEDLINGS

Accordingly, frequency index (percentage of area stocked) was checked in the following manner. In addition to tallying reproduction on quadrats at half-chain or one-chain intervals along parallel strips, the usual method of study designated in this paper as the quadrat-at-interval method, a tally was made on strips of contiguous quadrats distributed over the same area in a similar manner. This tally simply noted the presence or absence of reproduction by individual quadrats, and furnished data from which to compute F. I.'s based on from five to twenty times the usual sample as obtained by the quadrat-at-interval method. These frequency indices, therefore, act as a standard against which to check the accuracy of the F. I.'s obtained by the quadrat-at-interval method, and a comparison of this sort for six cut-over areas is shown in Table I.

TABLE I. *Check of frequency indices*

Method of Sampling	Cut-over Area Number											
	1		2		3		4		5		6	
	F. I. Basis		F. I. Basis		F. I. Basis		F. I. Basis		F. I. Basis		F. I. Basis	
	%	Quads	%	Quads	%	Quads	%	Quads	%	Quads	%	Quads
Quadrats contiguous.....	90	468	92	782	84	913	92	479	69	759	86	507
Quadrats at intervals.....	88	71	100	45	96	96	98	109	77	123	100	29

The reasonably close agreement of these figures indicates that the quadrat-at-interval method gives sufficiently accurate results in spite of the meagerness of the sample. The significant differences, however, show the need for caution in deciding the relative merits of two cut-over areas on the basis of differences in frequency index. Such differences might be attributed, in part or in whole, to accidents of sampling as well as to dissimilarity in conditions on the cut-over areas or in methods of cutting.

AVERAGE NUMBER OF SEEDLINGS PER ACRE

Checking the values for average number of seedlings per acre proved a much more difficult task. Statisticians (Student, '08) offer a very definite method of checking the accuracy of averages through the use of the probable error concept. But it is generally assumed that this statistical measure is directly applicable only to normal or nearly normal frequency distributions, illustrated in figure 1, A, in which the individual values obtained in sampling are distributed around the average value in an orderly progressive fashion, though it is also held probable that the deviation from normality

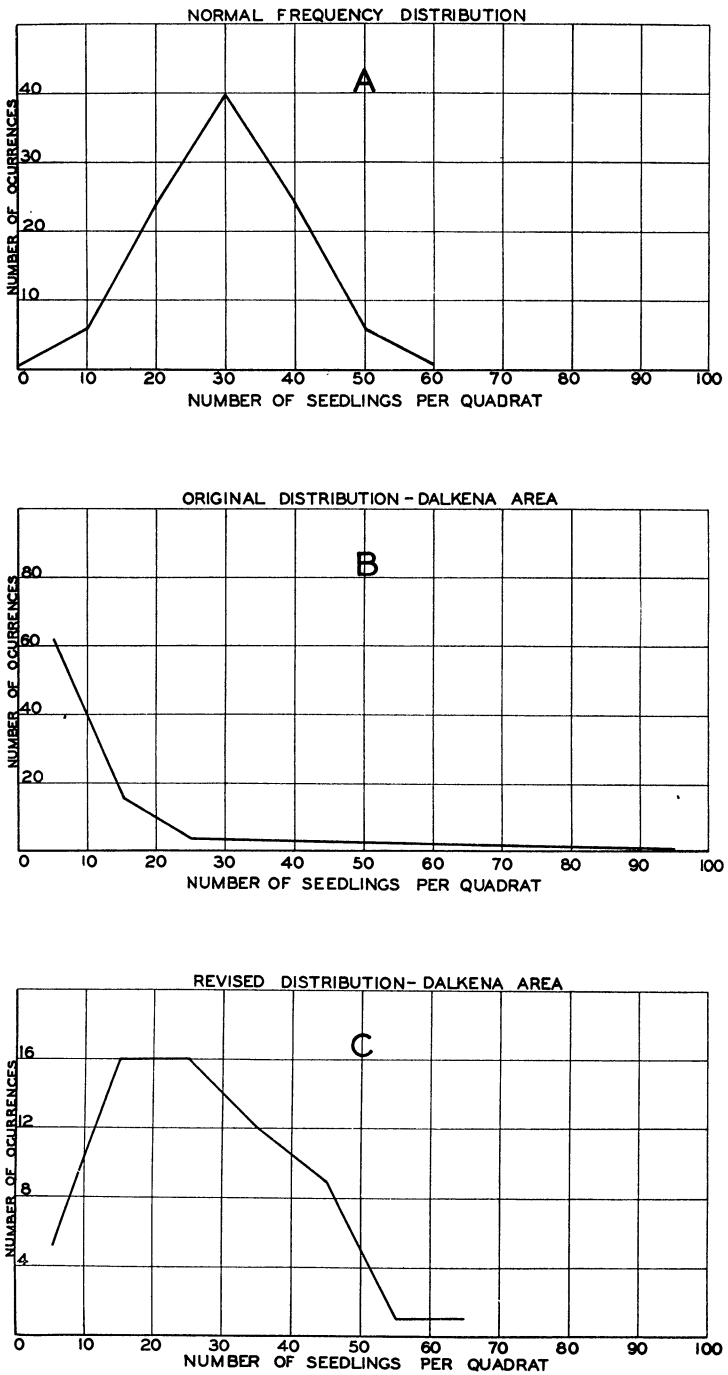


FIG. 1. Types of frequency distributions.

must be extreme to lead to serious error. In this study the frequency distributions are of an extreme type, being very much skewed in a plus direction. This type of distribution, based on the data for one of the cut-over areas studied, is shown in figure 1, B. Ordinary statistical methods for measuring the accuracy of averages cannot be applied accurately to this type of distribution, and it was necessary to convert these distributions to normal or more nearly normal distributions before such checks could be made.

METHOD OF TESTING DISTRIBUTIONS

A review of available statistical literature failed to suggest any method of testing the accuracy of averages obtained from such J-shaped distributions, or of converting such distributions to more normal proportions. Quartile deviation is the measure of dispersion often recommended for use with skewed distributions (Mills, '24), but this obviously is not applicable to the arithmetical average, the item of major interest in this particular study. It was necessary, therefore, to develop methods of treatment applicable to this extremely skewed type of distribution. Close study of the frequency curve in figure 1, B suggested certain steps that finally led to successful treatment. Although it was apparent that the definite skewness of this curve was the result of a combination of causes, the very definite J-shaped character of the curve was due chiefly to the fact that the average number of seedlings per quadrat was so small as to place the peak of the frequency curve very close to the zero point. The solution seemed the use of a larger quadrat containing on the average a greater number of seedlings. This would push the peak of the frequency curve in a plus direction and eliminate in large measure the J-shaped character of the distribution. There are numerous objections to the use of any quadrat other than the mil-acre as a field unit of measure, but none whatever to the use of a larger unit in the office analysis. Consequently, mil-acre quadrats were selected at random, arranged in groups of four or eight quadrats and the total sum of seedlings for each of these groups used as the number of seedlings per new unit measure.² This grouping had the same effect as if the field quadrats had been four or eight times as large and only one-fourth or one-eighth as many had been installed. Note that groups of 4's or 8's were used simply as a matter of convenience. The number of mil-acres incorporated in each group might have been any number desired, the sole criterion being that the number in each unit must be large enough to move the average number of seedlings per quadrat, and hence the peak of the frequency curve, a reasonable distance away from the zero ordinate.

This method of grouping eliminates the J-shaped character of the distribution, but it also reduces the number of quadrats on which the frequency curve is based and tends to produce weak and erratic distributions. To

² This method of grouping was originally suggested to the author by Mr. Donald Bruce.

overcome this objectional feature, this procedure of grouping was repeated any desired number of times, the entire set of original mil-acre values being used in each series, but the individual units in each series being formed by new combinations of different mil-acre values. In this way a new set of values was built up, the number of quadrats in this array being steadily increased by additional combinations of the original data until these values produced a reasonably smooth frequency curve. This type of distribution is shown in figure 1, C. Notice that this curve is still skewed. It was found impossible to entirely eliminate this factor, but the distribution is now near enough normal to permit the application of ordinary statistical checks with reasonable safety.

The use of the same basic data over and over in building up this new series of quadrats raised some question as to the accuracy of this process and its consequent effect on the probable error. Accordingly, a check was made of the effect of this process. The values in Column 2, Table II, show very definitely that as the number of combinations increases, that is as the same basic data is used over and over an increasing number of times to form values for new quadrats, the probable error appears to decrease with each additional repetition, changing from 11.1 per cent (the best available figure for probable error based on an average of the probable errors of six individual groupings by 4's or 8's) to 3.5 per cent on a basis of ten such combinations.

TABLE II. *Check of probable error computations*

Number of Combinations (1)	Uncorrected Value (2)	Probable Error Per Cent	Corrected Value (3)
1	11.1°		11.1°
3	6.5		11.2
5	5.1		11.4
7	4.3		11.4
10	3.5		11.1

° Most reliable figure; average of six probable errors each based on one combination by 4's or 8's.

This reduction is obviously an inaccuracy introduced by the repeated use of the basic data in various combinations, for ordinarily the probable error for this array would remain in the neighborhood of 11.1 per cent unless changes were introduced directly into the basic data. It was reasoned that the decrease in probable error must be directly related to the square root of the number of combinations and that this error could be eliminated by multiplying the probable error of an array by the square root of the number of combinations. This assumption was checked empirically and found correct. The corrected values for probable error listed in Column 3, Table II, were derived by multiplying the uncorrected values in Column 2 by the

square root of the corresponding number of combinations. Note that the corrected values are all close to 11.1 per cent, the most reliable value for this array. It is possible, therefore, through the use of this correction factor, to obtain the benefits of a smoother frequency distribution and a stronger basis in number of quadrat values without introducing inaccuracies into the computations for probable error. The accuracy of this method of treatment has not yet been checked on purely theoretical grounds, but the empirical check here given seems sufficient evidence that the method is fundamentally sound.

USE OF METHOD ON FIVE CUT-OVER AREAS

It is now possible by the use of these methods to convert the J-shaped frequency distributions, probably typical for similar ecological and silvical studies, into more nearly normal distributions, to which it is permissible to apply statistical checks. Accordingly, five cut-over areas were selected, the erratic measurements rejected in the usual manner (Bruce, '24), except that the skewness required the treatment of plus and minus deviations in separate groups, and the frequency distributions revised by the methods just described. The probable errors for average number of seedlings per acre were computed from these revised distributions. These probable errors, together with the other pertinent data, are listed in Table III. As the selected group of areas embodies several types of cutting, and both large and small areas, and as the samples collected on these areas vary in size from the minimum sample, .1 per cent, to the maximum sample, .8 per cent, the errors to which the averages of these areas are subjected should be fairly representative.

TABLE III. *Probable error of average number of seedlings per acre*

Cut-over Area Designation	Type of Cut-over Area	Amount of Total Area in Sample	Average Number of Seedlings	
			Number	Probable Error
		Per cent	Per Acre	Per cent
Dalkena	Shelterwood	0.8	8,300	7.7
Cathcart	Clearcut with Seed Trees	0.4	5,600	9.7
Ryrie-Wright	Shelterwood	0.2	14,800	8.0
Beardmore	Clearcut with Seed Group	0.2	9,500	6.9
McManimim	Clearcut with Seed Trees	0.1	13,200	9.6

These probable errors have a very definite and significant meaning. For example, on the Dalkena area the average number of seedlings per acre is estimated as 8,300 plus or minus, a probable error of 7.7 per cent. This means that this estimated value of 8,300 seedlings per acre, based on the very small sample of .8 of one per cent of the total area, is probably within 7.7 per cent, and almost certainly within 23.1 per cent (three times the

probable error) of the actual number of seedlings per acre that would be secured by a one-hundred-per-cent cruise of the cut-over area. This statement is based on the usual statistical definition of probable error, namely, that if each cut-over area were resampled, the new samples consisting of the same number of mil-acre quadrats as before, distributed in a similar manner, the new averages would fall within the range formed by the present average plus or minus the probable error in approximately 50 per cent of the cases, and within a range of the present average plus or minus three times the probable error in practically all or approximately 95 per cent of the cases.

The practical value of these probable errors is apparent. First, they offer assurance that the method of sampling employed has given averages accurate enough to insure a true picture of reproduction conditions, for all of the probable errors in this group are less than 10 per cent. Second, the probable errors show clearly that in weighing the merits of two cut-over areas, differences in values of average number of seedlings per acre of less than ten per cent are probably not significant (these can very easily be due to accidents of sampling alone) and that even differences of as much as 25 per cent must be classed as significant only with reservation.

LOCATION OF QUADRATS

There are two other matters of interest that might be mentioned in connection with quadrat sampling of cut-over areas. First, that it is essential to distribute the strips very thoroughly over the area. Errors as high as 60 per cent were incurred by concentrating strips on one portion of the area as opposed to distributing these strips at wider intervals over the entire area. This is in agreement with the conclusions reached by Gleason ('20), who, in studying the location of quadrats in ecological studies, found that the use of one-fourth of the data in contiguous quadrats, that is a concentration of the sample, resulted in an error of 10.7; while the use of one-fourth of the data in non-contiguous quadrats gave a corresponding error of only 2.7.

The second matter was that within certain common-sense limits, given the same number of mil-acres per unit of cut-over area, the greatest accuracy was obtained by distributing the quadrats along closely spaced strips with larger intervals between quadrats as opposed to widely spaced strips and smaller intervals between quadrats. This statement is based on a study of the effect of distribution of strips on four cut-over areas. The average error introduced by using only half the data with twice the usual interval between quadrats was 17 per cent, as compared to an error of 32 per cent incurred by using the same amount of data with twice the usual distance between strips.

SUMMARY

The purpose of this paper has been to discuss the accuracy of quadrat sampling as applied to reproduction studies in the western white pine type, and to discuss methods by which this accuracy can be measured. In general, the methods used in this study consisted in counting reproduction on mil-acre (6.6 feet square) quadrats distributed at one-half or one-chain (33 and 66 feet) intervals along parallel strips 2.5 to 10 chains apart. This quadrat-at-interval system, giving a sample of from .1 to .8 per cent of total area, was found to give satisfactory values for both frequency index (percentage of area stocked) and average number of seedlings per acre. In checking the values for average number of seedlings per acre, a method is suggested by which the J-shaped frequency distributions, probably common in similar ecological and silvical studies, can be converted into more nearly normal distributions and so strengthened as to permit the application of the probable error concept with a reasonable degree of safety. Indications are given that in sampling by the quadrat-at-interval method it is essential to have the parallel strips well distributed over the area, and that when only a limited sample can be taken the tendency should be to lengthen the interval between quadrats rather than the distance between strips.

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