A Canopy-Coverage Method of Vegetational Analysis

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THERE IS as yet little tendency toward standardization of the methods used in vegetational analysis. Most workers can find an area of agreement in that a mere taxonomic list for a piece of vegetation does not assume much synecologic importance until each kind of plant is evaluated quantitatively, but the methods of performing the latter are varied, each having an ardent group of advocates. A major cause for this divergence of opinion is that objectives of investigators differ, as when one wishes an appraisal of the amount of merchantable timber on an area, another wishes to evaluate the influence of grazing upon the composition of a pasture, and still another desires to put on record as complete a description as possible of a piece of virgin vegetation before it is destroyed.

A second cause of divergence in methodology is that all categories of plants are not equally amenable to appraisal by the same technique. Trees can usually be counted, but counting is impractical where rhizomatous and caespitose taxa[1] grow together in a community; line interception is excellent for cushion plants and low shrubs, but is impractical for annuals.

Differences in the outlook of the investigator are also important. Some botanists seek only a table of statistics showing the present composition of dominant trees in a stand, and in consequence ignore all stems under one inch or even under four inches in diameter. The statistic here seems to have become the end point in the process, yielding little to compensate for the labor expended in its attainment. Others look upon the same trees as a dynamic population and accordingly insist upon a type of data that will indicate successional trends. These workers keep separate the data for all age classes with the purpose of gaining clues as to the autecologic traits responsible for the different degrees of success of the various taxa in time and space, thus striving for an interpretation of the statistics. The methods followed by these groups are likely to be different, because their philosophies and concepts differ.

A fourth problem is raised by the perennial quest for a new method of getting accurate and meaningful data with a minimum expenditure of time. Actually less than one new technique appears in a decade, whereas each year

[1] A taxon is a "taxonomic group" or "entity," regardless of taxonomic level.

brings a flurry of allegedly "new" methods which are either pointless modifications of an old idea or are innocent rediscoveries. In comparison with Europe, American synecology is topheavy with suggested methods, but deficient in communities represented by substantial quantitative data.

During the past decade the writer has had to choose a method to be used consistently in semi-desert, grassland, and forest vegetation of eastern Washington and northern Idaho. The primary purpose of this paper is to describe the method. No part of the procedure is new, so that the paper is largely an exposition of the *combination* of techniques as employed, with a discussion of the philosophy behind their selection.

Broad Objectives

A major objective of the series of studies is to evaluate each taxon in terms of its relative influence in the ecosystem—by producing food and cover for animals, by modifying soil and microclimate, and by competing with other taxa for matter and energy. Acceptance of the ecosystem concept makes this objective especially desirable.

A second objective has been to choose a method whereby plants of widely different life forms and sizes could be compared on the same basis. It is felt that we have too frequently adopted a philosophy, even in theoretical synecology, that only the most abundant dominants are worthy of study, although the literature contains evidence that this is a dangerous assumption even in the most practical studies (Klapp, 1935; Parker, 1953). A satisfactory method, therefore, is one with sufficient versatility to evaluate the widest diversity of life forms of plants so that they can be compared as to relative influence, on as direct a basis as possible.

A third objective is to sample with sufficient accuracy so that the finer details of vegetation composition may be studied carefully in relation to quantitative analyses of environmental factors, and so that successional trends can be evaluated as soon as they are measurable.

A fourth objective is efficiency. A good method is one which provides reproduceable statistics with a minimum of field time, and it need be no more accurate than the heterogeneity of vegetation warrants.

It is highly doubtful if any method will ever be devised that meets all these requirements to a perfectly satisfactory degree, but for the present we can select those procedures that come the closest to doing so.

Principles of Sampling

The following principles were used as a guide in selecting the details of procedures for satisfying the above objectives.

1. The two-dimension plot method is superior to linear or plotless techniques, since it yields "more complete information about the community as a whole" (Lindsey, 1956), and, as it allows more taxa to be compared at each point of observation, it enhances opportunity for their comparison and correlation.

2. A series of small samples is superior to a single large one in the stand. They allow the sampling to encompass floristic variations from place to place over the stand without studying all the intervening area; they allow study of permanent plots which need not be trampled on at each visitation; and they allow an evaluation of frequency.

3. Adequacy of sampling of a stand is better achieved by increasing the number of plots rather than their size. Keeping plots small reduces observer error since the accuracy of estimation declines when the size of the observational unit exceeds that which can be seen without moving the eyes, and adding more plots, if scattered, allows better representation of the stand.

4. Elongate plots are superior to isodiametric shapes in that there is less possibility of a single plot coinciding with, or completely missing, the scattered isodiametric families by which most taxa are represented in a stand.

5. Large estimation classes are reasonably good assurance against significant personal error,[2] yet when applied to many small plots, they yield relatively precise averages. Much valuable field time can be wasted by attempting to make highly precise estimates using small class intervals.

6. The series of plots used to sample one stand of vegetation must all fall within an area so uniform[3] that intrinsic environmental diversity cannot be suspected as causing variation from place to place. The distribution of samples should trend along contours rather than cross them, for soil series commonly occur in belts that parallel contours, and if one accepts the ecosystem concept, a homogeneous population of plots may never overlap two soil series. This is not to deny that contiguous soils may support apparently identical vegetation, but to point out that such a situation needs proof and should never be assumed. Should a trail with its characteristic border of specialized weeds cross an otherwise homogeneous tract of vegetation, the particular plots which fall upon the trail can be omitted. (The trail complex deserves special study rather than inclusion in a large plot where the resultant statistics would suggest a homogeneous mixture of species that can and those that cannot endure trampling.) Likewise plots falling on the area occupied by a tree stem, a boulder, or an

[2] Personal error is high when a precise estimate of a large sample is attempted. "Square-foot density" estimates may vary 100 per cent between two observers (Smith, 1944). Weight estimates are sometimes 20 per cent in error (Schwan and Swift, 1941).

[3] The uniform area may be in the form of a matrix enclosing small islands of microenvironment that support communities with distinctive parameters.

ant nest should be ignored, if one is interested in the average composition of the mosses, herbs, and shrubs that constitute the matrix community.

7. Vegetational structure is variable owing to an element of chance in the timing of dissemination in relation to opportunities for seedling establishment, etc.; therefore, precise measurements are not warranted except where the objective is to study successional trends by repeated analysis of a very small area.

8. Several kinds of records may be made of the plants found in a sample plot (e.g., number of individuals, dry weight of shoots, canopy coverage,[4] etc.), and each attribute is sufficiently independent of the others so that one kind of statistic cannot be reliably calculated from the records of another. We must make a decision as to which measurements serve the purpose of the investigation.

9. Canopy coverage "is the most important single parameter of a species in its community relations" (Lindsey, 1956).

10. A two-dimensional estimate of that part of space over which a plant exerts its influence is best approximated by a polygon described about the periphery of the undisturbed canopy. Meticulous definition of allowable discontinuities is unrealistic, for it penalizes certain plants on account of their phyllotaxy or accidents of dispersal of foliage sprays. Furthermore, important influences are exerted beneath these discontinuities by the root systems, which are at least as extensive in a horizontal direction as are the canopies (e.g., Fig 4).

11. Most communities are composed of superimposed layers of plants, so that the ground is in reality covered more than once in many places; therefore, any attempt to make the total coverage of all taxa, plus any bare ground, add up to 100 per cent is unrealistic. Furthermore, the sum of all canopy-coverage values provides a comparative index of productivity at least for closely related ecosystems.

12. In most plant communities the taxa attain their maximal seasonal development at different times, hence a series of plots must be studied at

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[4] The looseness of usage of terms such as "cover," "density," "composition," etc., is a constant source of confusion, and until methodology becomes more standardized, definitions should always be given. For the present paper, the following definitions are offered.

Density—number of individuals (not organically connected, unless specified) to be found in a given space.

Canopy cover—percentage of ground covered when a polygon drawn about the extremities of the undisturbed canopy of each plant is projected upon the ground, and all such projections on a given area are summed. In the old and abandoned "square-foot density" method, the foliage was usually compressed until one could not see through the mass, whereas other methods simply define the maximum size of space between contiguous foliage sprays that may be ignored. The degree of compaction thought desirable among different workers varies considerably and has a strong influence upon the data.

Basal area—the aggregate cross-section area of all stems, or tufts of a caespitose grass, as measured at the ground surface or at a stated height above the ground, e.g., 1.5 for trees, or 5 mm for herbs.

different seasons so selected as to permit the evaluation of each taxon near the time when it is exerting maximal influence upon the remainder of the ecosystem.

13. A separate census of all age (or size) classes is essential if the sampling is to yield quantitative information on population dynamics, i.e., the successional trend of each taxon.

14. Locating plots at points along a tape stretched between two iron stakes is the easiest means of insuring an ability to relocate them. Plots should usually be laid out so that they can be tallied again at some time in the future, since many opportunities to observe the effects of unanticipated weather, fire, or grazing phenomena have been lost for lack of means of relocating plots that had been studied for another purpose earlier.

15. Systematic placement of plots along a type yields reproduceable statistics with inspection of a minimum number of plots.

Method

In this section the method will be described, the reasoning behind certain of the steps will be discussed, and some evaluations against alternative procedures given.

Selection of study area. The first step in the field is to select an area for sampling that is representative of the stand. The landscape must be divided into units (stands) so small that within each unit topography and soil do not differ sufficiently to be an obvious cause of vegetational differentiation, and all parts of the unit must have had the same history, i.e., degree of animal influence, age since last burning, etc. The more compact the area over which the sampling is done, the more precisely can vegetation composition and structure be related to a particular soil profile (Gaines, et al., 1954; Goode, 1953/4; Harris and Scofield, 1920; Heinicke and Batjer, 1931) and microclimate. This matter of selecting a unit of maximum homogeneity in sampling natural vegetation is frequently not accorded the importance it deserves. It conditions the value of all subsequent steps, and is essential if biometric techniques are to be applied properly. Objectivity is important in all subsequent steps, but it has no place here.

When a representative area is selected, a steel tape is stretched across it and held under tension between two stakes by means of a spring or steel pins. For each site it is necessary to record the locations of the stakes with reference to permanent and conspicuous features of the area, record which end of the tape represents zero, record the side of the tape on which the plots are to be located, and indicate the points on the tape which form the sides of the first and second plots. The latter, which fall at fixed intervals, are objectively

located in that the observer has no influence over the particular plants that are included in each.

Plot shape, size, and numbers. Although the elongate plot is superior, there are practical limitations to lengthening it because (1) very long plots are not easy to lay out, and (2) the more periphery is increased the more frequently the observer must pause to make close decisions as to whether a plant is inside the plot margin or not. The human tendency seems to be to include too many plants in case of close decisions (Mahalanobis, 1946).

A 1/10 m^2 plot (20 x 50 cm) has been found very satisfactory. As size is increased beyond this, it becomes difficult to see the entire area at once, and if the eye must be moved about, an element of memory increases the error involved in any type of estimation. On the other hand, as plot size is decreased below a 1/10 m^2, the numbers required for an adequate sample increase rapidly. Parker (1951), for example, has recommended only 300 plots, ¾ inch in diameter, but then admits that he must rely heavily upon supplemental notations to get even a subjective appraisal of all but a few common taxa. Sharp (1954) found that 300 such "loops" require 2.5 - 3.0 hours for their first tally, and half as much for subsequent tallies. The procedure in this case requires as much time to get objective data on the most abundant plants as is needed to tally 40 plots 1/10 m^2 in size, which is adequate for a much larger percentage[5] of the total flora (Fig. 1). Forty plots 1/10 m^2 in area sample the equivalent of 14,000 loops.

Johnston (1957) also tested the loop method and found 200 - 3,400 loops necessary to reduce error for major grassland dominants to within 10 per cent of the true mean, and the number required for an equally accurate estimate of the minor species was too astronomic to calculate!

Reducing plot size to a few mm in diameter (point-frequency method) increases the magnitude of the problem still more. Crocker and Tiver (1948) consider the remarkably low number of 300 - 500 points adequate for most of the common grassland dominants, but considered the method impractical when the vegetation exceeded a height of 15 cm. Whitman and Siggeirsson (1954) found that 1,400 points or more are required to reduce sampling error below 10 per cent for even the major taxa of North Dakota grasslands. Johnston (1957) found 1,200 - 4,320 points necessary for major species, with 22,560 to 38,940 necessary for minor species. As usually applied, Leasure

[5] Number of taxa evaluated in relation to the total flora of the stand is a statistic apparently not provided by North American synecologists. Complete records for 30 stands of widely different vegetation types in eastern Washington and northern Idaho show that as an average the method described will evaluate 22.5 taxa, leaving nine unencountered. Judging from Figure 1, the method herein described provides a reasonably reliable evaluation of taxa with as little as 0.5 per cent canopy coverage. The nine taxa unencountered are mostly rare plants with even less coverage, yet it is important that their presence be indicated (see Table 1).

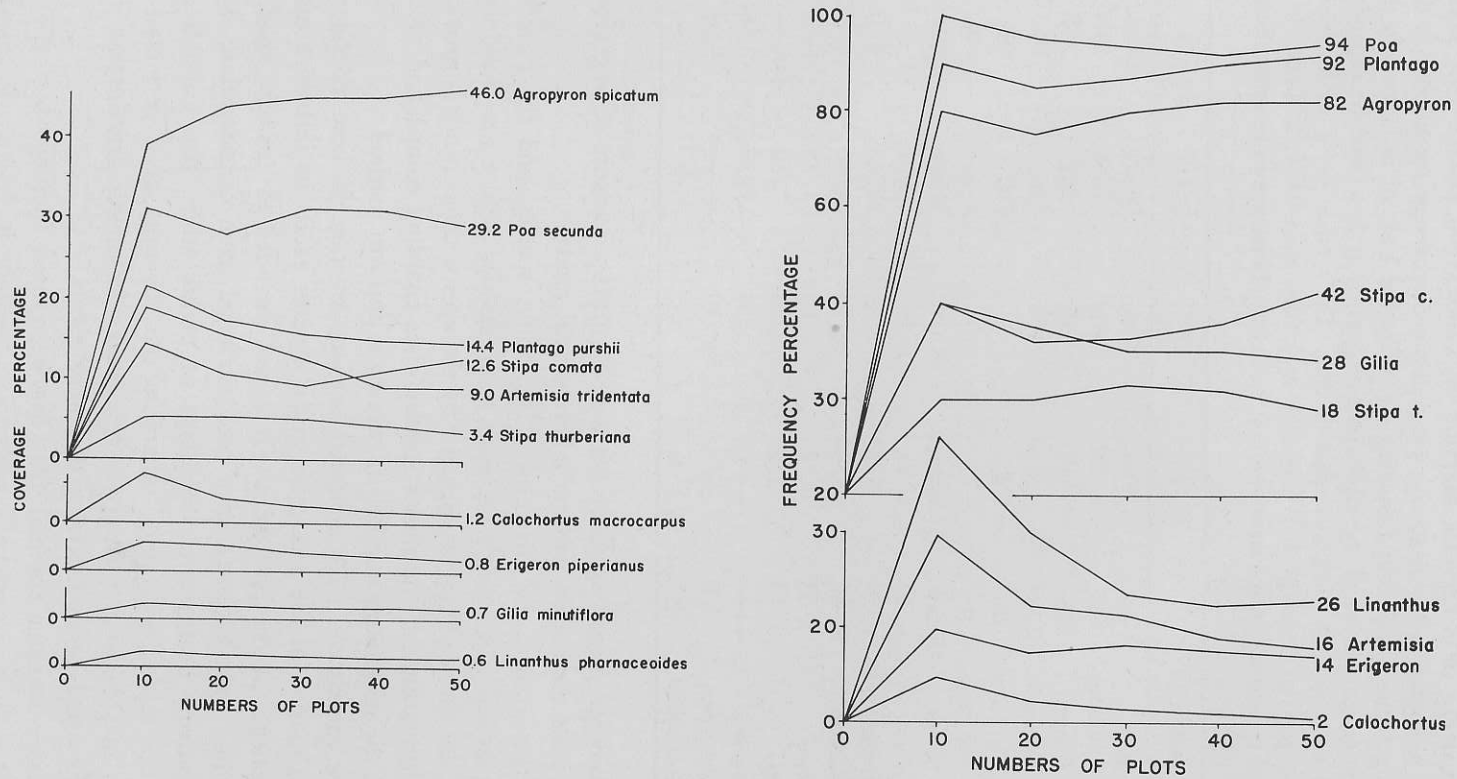

Figure 1. Changes in canopy coverage and frequency with increasing amounts of area studied in one stand. Taxa with less than 0.6 per cent coverage have been omitted. The first 10 plots happened to underestimate coverage of the dominant *Agropyron,* hence there was space for above-average representation of most subordinates. The opposite phenomenon is also equally probable.

TABLE 1. EXAMPLE OF A CONCISE METHOD OF TABULATING SYNECOLOGIC DATA

The figure preceding each / is average per cent canopy coverage for all plots in the stand; following figure is per cent frequency (coverage the basis of inclusion) in the same plots. The upper section of the table containing physical data could be expanded indefinitely to accommodate additional types of data. The symbol +/+ indicates occurrence in the plots at coverage and frequency values less than 0.6%; a single + is used to indicate occurrence in the stand without sufficient abundance to be encountered in the plots.

Stand Number		1	2	3	4	5
Location	State	Wash.	Wash.	Wash.	Wash.	Wash.
	Township	22N	7N	19N	16N	19N
	Range	22E	33E	30E	24E	33E
	Section	17	18	34	16	19
Slope	Direction	0	SW	S	NW	8
	Per cent	0	15	10	2	0
Soil	Series	Clearw.	Ritzv.	Ritzv.	Ritzv.	Ephrata
	Class	si lo	si lo	si lo	si lo	f sa lo
Artemisia tridentata		8/20	5/14	11/38	16/42	9/16
Agropyron spicatum		53/80	44/84	36/70	41/90	46/82
Bromus tectorum		5/68	+/2	1/35	1/35	+/2
Phlox longifolia		2/15	2/28	12/65	7/60	———
Erigeron piperianus		———	———	2/35	2/38	1/14
Tetradymia canescens		2/8	+/+	2/10	———	+/+
Balsamorrhiza careyana		+	+	+	+	———

(1949) considered point frequency no more accurate a measure of vegetation composition than estimation without a mechanical guide.

Clearly the crux of the difficulty is the minor species, and the problem of obtaining an adequate sample increases geometrically as plot size is reduced. The largest plot that can be encompassed by the eyes without moving provides the most information for the minor species, thus enabling comparison of the coverages of the maximum number of taxa by a uniform method.

Coverage estimation. As indicated earlier, coverage is here considered as an approximation of the area over which a plant exerts its influence upon other components of the ecosystem. It is not intended to estimate shading of the ground. Inflorescences have been excluded from consideration, since they are relatively evanescent. Seedlings of plants other than annuals are ignored if not tallied separately, otherwise the coverage of a perennial in arid regions may be very high for a few weeks following germination and preceding the usual heavy mortality of young plants.

The canopy-coverage method that has been used involves basically an evaluation of each taxon as to its percentage coverage in relation to quarters

of the plot area, i.e., whether the coverage is between 0-25, 25-50, 50-75, or 75-100 per cent. When such a simple system is tried, however, two deficiencies appear immediately. Many plants have very little coverage in any plot, so that in later summarization of field data the use of the midpoint of each coverage class in the calculation of averages greatly overestimates their coverage. Consequently, a special coverage class of 0-5 per cent is split off the 0-25 per cent category. Also, it will be noted that any plant which covered all of every plot could never have more than 87.5 per cent coverage (midpoint of the 75-100 per cent category) by this method of calculation. Therefore, a 95-100 per cent category is segregated from the 75-100 per cent area. The six coverage classes with their ranges of value, and the midpoints used in calculations, then become:

	Per Cent Coverage	
Class	*Range*	*Midpoint*
1	0-5	2.5
2	5-25	15
3	25-50	37.5
4	50-75	62.5
5	75-95	85
6	95-100	97.5

Use of the midpoints for interpretation of the field notations rests upon the assumption that actual values tend to be symmetrically dispersed about these points. The method allows sufficient precision to measure small successional changes because only a few of the records barely within Class 2, for example, would have to drop a little below this level to cause a shift in the averages for the entire series of evaluations for one taxon.

With coverage classes defined so broadly, there should be little chance for consistent human error in assigning coverage classes. It is reasonable to assume that in this method, observer error is smaller than normal variation in different parts of a stand that must be accepted as homogeneous for synecologic study.

A plot frame 20 x 50 cm (inside dimensions) is placed briefly at fixed intervals along the tape, while the taxa included or overhanging[6] and their coverages are recorded (Fig. 2). It is helpful to paint the frame so as to divide it into quarters crosswise, then in one corner of the frame indicate two sides of an area 71 mm square (Fig. 2). Thus, there are always available for reference areas equal to 5, 25, 50, 75, and 95 per cent of the frame. A

[6] If individuals are to be counted (density technique), plants that merely overhang the plot must not be tallied, or there will be bias in favor of the larger taxa. Only the position of the center of the stem may be used as a criterion. But where *coverage* is used and *vegetation influence* is emphasized, bias is no problem, and overhang is properly counted.

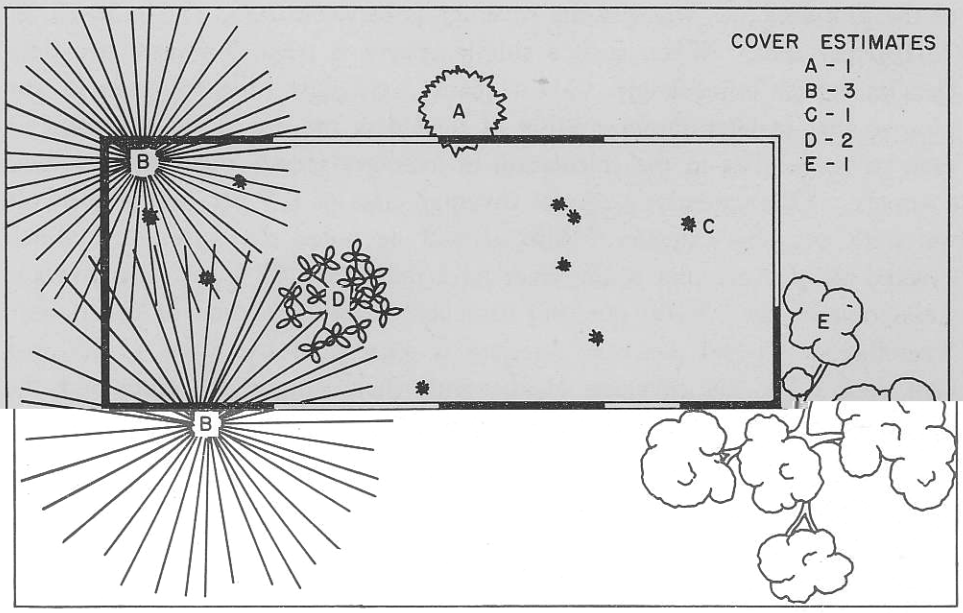

Figure 2. Diagram illustrating method of estimating canopy coverage. The biologic soundness of using the vertical projection of a polygon drawn about the extremities of the plant canopy is illustrated by E, which, by accident of foliage arrangement, actually has no leaves directly above the plot frame. A plant of this type probably exerts at least as much influence on the 20 x 50 cm portion of an ecosystem as does A.

frame this size is sufficiently rigid if made of 3/16″ steel. Sharpened legs 3 cm long are welded to each corner, these holding the frame in place while the investigator observes and records the contents of each plot. The legs also permit tallying the condition of the ground surface (bare ground, cryptogam crust, litter, living vascular plants,[7] etc.) which adds to this technique the chief advantage of the point-frequency method. On account of the sharpness of the legs, the frame is stored in a plywood box just large enough to accommodate it. (For class use, frames with blunt legs 2 cm long are safer, and several of them may be transported in small space.)

Adequacy of sampling. In studies of an experimental character where one aims to bring out quantitative differences between closely similar vegetation of two areas, one experimental (e.g., grazed, fertilized, burned, etc.) and the other a control, biometric techniques are useful in estimating the degree of significance of the differences found. Also standard errors are often

[7] One satisfactory method of tally is to record a mark for each of these surface types that makes contact with the leg anywhere about its periphery. The contacts can be expressed as a percentage of the total legs examined.

calculated to judge the reliability of estimates in nonexperimental work. However, biometry is not always as satisfactory in natural vegetation as in the large and uniform stands with which an agronomist works. Frequently vegetation is so heterogeneous that a sample large enough to satisfy a mathematician is unrealistic in relation to (1) the time most investigators feel justified in spending in one stand when variability among stands demands that many be studied, (2) the frequently limited size of stands that may be considered as homogeneous, and (3) the degree of accuracy needed for the type of conclusions desired.

Opinions vary widely as to the best method of distributing sample plots within one homogeneous vegetation unit. Many continental European phytosociologists carefully select the position of each sample plot so that it represents their concept of a representative spot, but this is almost never done in the English-speaking countries. Among workers in the latter regions, some prefer strictly systematic distribution as this provides a reproduceable statistic with study of a minimum number of plots (Finney, 1948; Osborne, 1942). But opinion within this group is then divided as to whether biometric techniques are applicable to systematic sampling (Hasel, 1938; Horton, 1941; Madow and Madow, 1944; Pearsall and Newbold, 1957; Salmon, 1953), or whether strict randomization is essential for biometric analysis (Bordeau, 1953; Cochran, et al., 1954). Neyman (1952, p. 82) does "not see any evidence to support the assertion that lack of randomization by itself is ruinous to statistical tests." Student, who considered systematic sampling more accurate than random, asserted that the chief disadvantage of applying conventional standard error calculations to systematically obtained data is that it tends to overestimate error, and this simply guards against overdrawn conclusions (ibid., p. 67). Resolution of the random vs. systematic argument seems purely a matter of opinion, for there is no bias inherent[8] in the application of statistics to systematic data (ibid., p. 76).

An intermediate position is that of workers who use restricted random sampling (one or more randomized plots within each major sector into which the entire stand is first divided) in an effort to improve plot distribution, yet remain within the limits of what they consider proper procedure for allowing biometric tests (Goodall, 1952; Pechanec and Steward, 1940). Finally, it is possible to take advantage of the efficiency of wholly systematic sampling avoiding these biometric controversies by an adaptation of the old species-area curve, which in its original application is useful only to test the

[8] Bias is a possibility in agronomic tests, however, since cultivation and fertilization tend to affect the field in parallel strips, and a systematic pattern might be devised that would parallel this orientation and not provide the same results as either randomization or another systematic arrangement that cut across the pattern diagonally.

floristic adequacy of sampling. An example of this procedure is given in Figure 1.

Tests in a wide variety of vegetation in Washington and Idaho have shown that 40 plots 20 x 50 cm, spaced about one plot diameter apart, give an approximation of coverage that appears satisfactory (Fig. 1), although it is not here recommended that this value be accepted everywhere without making tests. There is now a considerable area of agreement among different workers using plots about 1/10 m^2, whereas a quarter of a century ago plots smaller than 1 x 1 m were almost never used by North American plant ecologists. In Swedish pastures where the vegetation is undoubtedly more uniform than in less artificial communities, 10 1/10 m^2 plots are considered ample (Anonymous, 1940), but in more natural vegetation, at least twice as many plots this size have been recommended. Cain (1943) found 20 plots 0.1 x 1.0 m adequate; Rice (1952) found 20 plots 0.32 x 0.32 m satisfactory; Kelting (1954) used 25 plots 0.32 x 0.32 m; Evanko and Peterson (1955) used 30 plots 0.2 x 0.5 m; Ovington (1955) used 50 plots 0.25 x 0.25 m; and Dix and Butler (1954) studied 80 plots 0.35 x 0.35 m per stand.

It takes from one-half to four hours to tally 40 such plots, depending on the complexity of the vegetation. When one starts a synecologic study, he can tally the first 40 plots, then with an hour or two of calculation can construct a set of curves such as shown in Figure 1, and determine if sampling is adequate for both rare and common taxa, and for the particular statistics he hopes to approximate. If the vegetation matrix is carefully subdivided into categories with closely similar parameters, there seems to be little need for further testing of the adequacy of sampling, for wherever it has been tested by the writer, the results from one stand of an association apply equally well to other stands of the same association. And it seems as though 40 plots this size are adequate over a wide range of herbaceous and shrubby vegetation, and for epigeous mosses as well (Higinbotham and Higinbotham, 1954).

The type of curves illustrated in Figure 1 suggests that for the stand studied, 40 plots provide a rather constant value, but the standard error for large scattered shrubs such as *Artemisia tridentata* is always high. For example, the mean and standard error of the five sets of coverage values used in the *Artemisia* curve in Figure 1 is 9.0 ± 4.1, whereas the means and standard errors for the other five major species range from *Agropyron* 46.0 ± 2.3 to *Stipa thurberiana* 3.4 ± 0.8. Since the minimal error curve and standard error suggest divergent conclusions with respect to adequacy of sampling, a study was made comparing the results of canopy coverage and line interception.

If coverage is consistently defined as a vertical projection of the outlines of the undisturbed foliage, line interception should give data identical with those of the canopy-coverage method here described, providing both samples are adequate. Seven parallel lines were tallied, the middle one being co-extensive with the base line, along which were distributed 40 or 50 coverage plots. Canfield (1941) found 800-1,600 feet of line adequate for similar vegetation, and Proudfoot (1942) recommended that the amount of intercept should exceed 100 x the diameter of the average plant canopy. From these studies, it seems safe to assume that 1,148 feet (350 m) of line used here serves as a reasonable basis for evaluating the adequacy of the plot technique in vegetation where canopies rarely equal one meter in diameter. The results of the comparison (Table 2) show that in only one out of the 21 comparisons did the difference in estimates by the two methods reach as much as 5.5 per cent, and only three times did the difference exceed 2.6

TABLE 2. COMPARISON OF RESULTS OBTAINED BY DIFFERENT METHODS OF DETERMINING CROWN COVERAGE

Stand	Shrub	% Crown Coverage Based on 350 m. line intercept	40-50 plots 20 × 50 cm	Direction and Degree of Difference in Plot Data
1	*Artemisia tridentata*	3.6	1.6	−2.0
	A. tripartita	16.1	21.6	+5.5
	Tetradymia canescens	0.5	1.5	+1.0
2	*Artemisia tridentata*	9.2	9.0	−0.2
	A. tripartita	0.1	0.1	0.0
	Tetradymia canescens	0.5	0.0	−0.5
3	*Artemisia tridentata*	10.6	12.9	+2.3
	A. tripartita	0.4	3.9	+3.5
	Chrysothamnus viscidiflorus	0.2	0.0	−0.2
4	*Artemisia tridentata*	23.1	24.8	+1.7
	Tetradymia canescens	0.4	0.3	−0.1
	Chrysothamnus viscidiflorus	0.1	0.3	+0.2
5	*Artemisia tridentata*	7.6	9.0	+1.4
	Tetradymia canescens	0.3	0.3	0.0
	Chrysothamnus viscidiflorus	0.2	0.0	−0.2
	C. nauseosus	0.2	0.0	−0.2
6	*Artemisia tridentata*	6.6	9.2	+2.6
7	*Artemisia tridentata*	9.4	5.0	−4.4
	Tetradymia canescens	0.1	0.0	−0.1
8	*Artemisia tridentata*	7.4	9.0	+1.6
9	*Artemisia tridentata*	11.6	12.0	+0.4

per cent. Apparently the standard error overestimates the amount of work needed to get a reasonable appraisal of the coverage of scattered shrubs when 40 to 50 1/10 m^2 plots are used.

Although synecologic conclusions based on 350 m of line and on 40 to 50 1/10 m^2 plots must be approximately identical, the two methods are not equally efficient. To tally 350 m of line takes much more time than to estimate coverage on 50 plots 20 x 50 cm (although for other types of vegetation the time relations may be reversed, Bauer, 1943); and what is more important, line interception is not as satisfactory a method for as many life forms of plants as can be sampled by the coverage method.

Presentation of the data. Another special advantage of the method is that the coverage entries made in the field can be used as a basis for calculating frequency[9] in the laboratory, hence give some information on ubiquity. As Brown (1954) says "frequency alone gives information on the distribution of species. When it is combined with other attributes of the plant, the evaluation of the importance of species is on a broader basis." High frequency may be associated with either high or low coverage, depending upon the degree of dispersion of the taxon. A common method of publishing taxonomic composition, coverage and ubiquity, in concise but independent form, is indicated by Table 1. The vertical and horizontal columns should be rearranged until the table shows the maximum of relationships among taxonomic groupings, and between these and environmental variables, which can be expanded considerably beyond the items appearing at the top of the example given. Since coverage is never reduced to a percentage based on the total for all taxa, the behavior of each may be compared through successive years and in different ecosystems without complications introduced by increases or decreases in other taxa.

Relation of canopy coverage to other analyses. The dry weight of forage per unit area is widely recognized as the most relevant datum for an accurate calculation of grazing capacity, but the clipping and weighing required to obtain such data are too laborious to warrant frequent determinations. A number of workers have attempted to establish conversion factors, sometimes achieving a measure of success (Arny and Schmid, 1942; Hanson, 1934; Julin, 1948; Shipley, et al., 1942), and sometimes not (Campbell and Cassidy, 1949; Hanson, 1934; Whitman, 1954). Preliminary testing of this idea

[9] Frequency has been based on (1) those plants with overwintering buds in the plots, (2) those with the centers of their axes in the plots, and (3) those which have any coverage of the plot. Each method will give somewhat different results for the same series of plots, but all are probably equally good as criteria of ubiquity, which is all that can be expected from frequency data. Number (3) above is the type of statistic yielded by the method of vegetation analysis that is here described.

has led the writer to agree with the latter group that the relations between different kinds of measurements of dominance as determined in one stand cannot be considered valid for another (Fig. 3). The ratio between dry weight and canopy coverage may be expected to vary with taxa, habitat types,

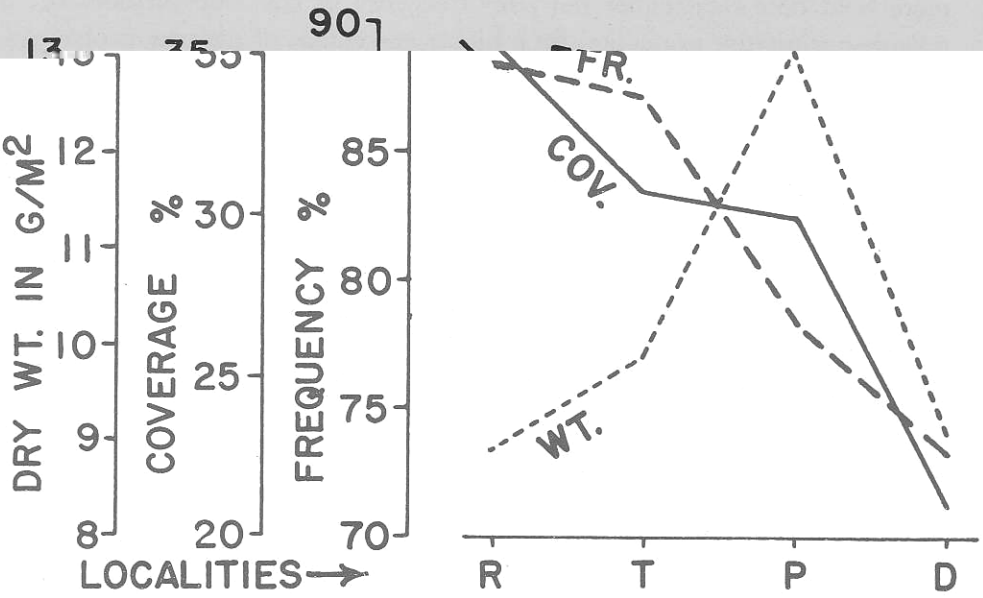

Figure 3. Relationships among dry weight of shoots, canopy coverage, and frequency of *Poa secunda* at four localities along the eastern edge of the Cascade Mountains in Washington. R and T represent stands on loess in very dry climate; P and D represent stands on glacial outwash in climates not so dry. Oven-dry weight includes only current season's shoots clipped within 5 mm of the soil surface as the inflorescences reached full size. Coverage is based on plots 20 x 50 cm, counting total foliage spread. Frequency is based on circular plots 1 dm^2, systematically spaced, counting only basal area. Five to seven m^2 were clipped in each stand, with other determinations made on same area just prior to clipping.

biotypes on different areas representing the same habitat types, stage of growth, and weather of different years.[10]

Other advantages and limitations. This canopy-coverage estimation technique becomes awkward as plants begin to exceed waist height, but is satisfactory for a wide variety of shorter plants, including shrubs, herbs, and bryophytes except those of grassland and semi-desert where the plants are

[10] Use by grazing animals is another variable. For this as well as any other method of evaluating coverage or amount of forage on an area being heavily grazed, it is necessary to erect exclosures during the growing season when the studies are made.

minute and the individuals of different taxa are intermingled. All are evaluated on the same basis so that direct comparisons in time and space, involving different workers and communities, can be made. The technique takes advantage of all the established principles favoring rapid and accurate sampling. It provides more information without requiring proportionately more field time than either the point-frequency or the loop method, i.e., a reliable quantitative evaluation for a higher percentage of the taxa is obtained, and their distribution as well as coverage is evaluated. With both the point-frequency and loop methods, a number of ways of tallying plants of different size and life form appeared almost from the first, so that results are not comparable between investigators and frequently between different types of plants sampled by one investigator. Canopy coverage avoids the very serious difficulties of the basal-area tally in that the problem of comparing rhizomatous grasses, caespitose grasses, single-stemmed bushy forbs, and shrubs is not encountered. It has the added advantage of being "more closely related to forage availability to livestock, than is basal" area (Amer. Soc. Agron., 1952). The coverage method compares directly with line interception, if coverage in both cases is defined as a line drawn about the margin of the canopy at its maximum spread. The advantages of the plot technique over line interception are: (1) ground surface data can be determined along with coverage, without addition of a second sampling technique, (2) less time is involved than in laying out lines, (3) a smaller area is required so that a maximum degree of accuracy can be achieved in correlating the specific composition of a sample vegetation with a specific type of soil profile, (4) more life forms are satisfactorily considered, (5) one can examine the plot data to test for natural affinities or repulsions among taxa, and (6) the plot records can be used to evaluate degree of ubiquity of each taxon through the stand.

A final comparison that is instructive is made in Table 3. For determining grazing capacity, dry weight is the most significant of the determinations here compared. A *Lupinus* plant may produce twice as much forage on only half the area covered by an *Agropyron* plant. Therefore, coverage is not a

TABLE 3. COMPARISON OF THREE METHODS OF EVALUATING QUANTITY OF SHOOT MATERIALS. PLANTS ON WHICH THESE MEASUREMENTS WERE MADE ARE ILLUSTRATED IN FIGURE 4

Single, fully developed plants		*Lupinus sericeus*	*Agropyron spicatum*	*Poa secunda*
	Air-dry wt. total shoot	100	52	1
Relative	Area covered by canopy	58	100	3
	Basal area, soil surface	9	100	10

reliable criterion of forage production between different taxa (or within one taxon, as shown earlier). If canopy coverage is inadequate for this purpose, basal area is infinitely worse, for two plants may have the same basal area (*Poa* and *Lupinus*) but differ 100-fold in dry-matter production. Basal area is not only a very poor criterion of forage production, but also of dominance (compare *Poa* and *Lupinus* in Fig. 4, keeping in mind their equivalent basal area). Major reasons why interest in basal area continues, with respect to herbaceous vegetation, are (1) that the evaluation can be made over a longer season than is possible for canopy-coverage or dry-weight determinations, (2) that the technique is satisfactory where frequent checks of permanent plots are needed to determine if grazing pressure is too severe for caespitose grasses, and (3) an assumption that basal area is unaffected by weather variation from year to year. What few data are available, however, show that the last assumption is not warranted, for in New Mexico the "tuft area" (= basal area at height of one inch) and " basal density" show considerable annual variations depending on the rainfall (Campbell, 1931; Lister and Schumacher, 1937; USFS, 1957).

The foregoing account concerns vegetation below eye level rather than overhead canopies. Although it is not as easy to make coverage estimates of trees as of lower plants, their coverage can be determined with special instruments. The most widely used of these is an adaptation of the periscope principle that has long been used by Finnish foresters (Savis, 1953) and has been advocated recently in North America (Buell and Cantlon, 1950; Garrison, 1949; Robinson, 1947). Other mechanical aids to determining the coverage of trees have been described by Buell (1936) and Lemmon (1956).

In pointing out the advantage of this canopy-coverage technique, the writer does not wish to impute the quality of perfection to it, but after designing the method to take advantage of the most useful principles of sampling, the difficulties that have been encountered in its application are considered relatively minor. Any mathematical objections are rather inconsequential if the coverage data are used only as a rough criterion of the two-dimensional area over which the different plant taxa exert an influence upon other components of the ecosystem, and the frequency data are used only as a criterion of ubiquity.

Summary

The objectives and principles of sampling vegetation are discussed and a canopy-coverage technique is described. Forty plots each 20 x 50 cm are spaced systematically along a tape, and the coverage, interpreted as a vertical projection of a polygon drawn about the undisturbed canopy, is estimated

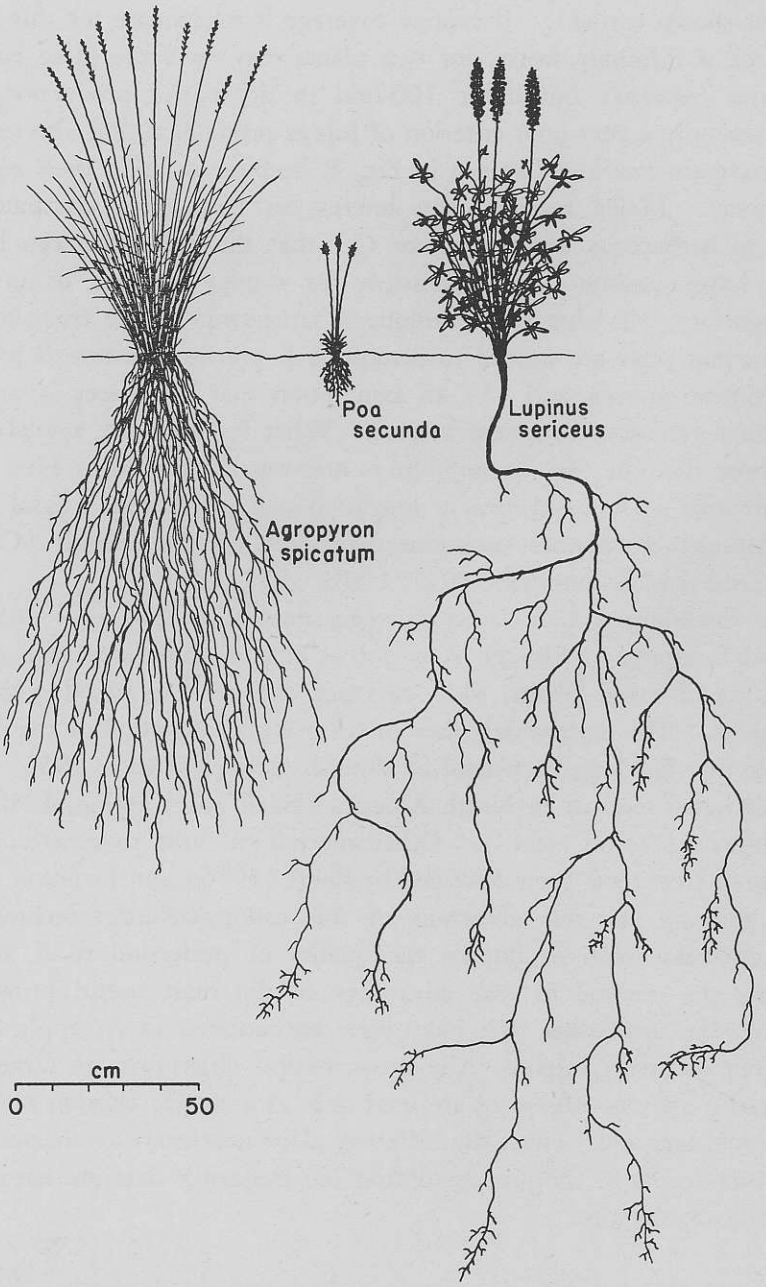

Figure 4. Diagrams of root and shoot systems based on measurements of representative shoots in field, with root systems added, to scale, from Weaver (1917).

separately for each taxon in each plot. Coverage classes recorded in the field are: 0-5, 5-25, 25-50, 50-75, 75-95, and 95-100 per cent. In subsequent calculations of average coverage for the series of plots the midpoint of each class is used. This method is applicable to a wide variety of vegetation

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