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THE POINT QUADRAT METHOD OF VEGETATION ANALYSIS : A REVIEW

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INTRODUCTION

The estimation of various properties of vegetation has commonly been dependent upon measurements from relatively small samples called quadrats. The accuracy of such estimates is governed by both the size and number of quadrats sampled (14). For a given amount of labour the greatest accuracy is achieved by decreasing the size and proportionally increasing the number of quadrats. The ultimate result of such a procedure of reducing quadrat size is a point, which has no area (14, 17, 19). Point quadrat analysis consists of moving a point at some defined direction through vegetation and recording presence or absence of a desired parameter.

This paper reviews the use of point quadrat analysis for the determination of floristic composition and pattern, aspects of canopy structure and light utilisation, together with considerations of statistical strategy.

BOTANICAL COMPOSITION

Change in botanical composition is one of the best means of studying ecological succession and trends in development of a pasture (14, 22, 59). The frequency of point-species contacts forms an ideal basis for such measurements. The technique originated in New Zealand (45, 46), apparently from a suggestion by Cockayne (19) on the validity of using a point, represented by a toe cap, as a sampling unit in tussock grasslands. Several early descriptions of the technique appeared (27, 46, 64) and subsequently Goodall (31) and Brown (14) have reviewed this method of botanical analysis.

Data records have been expressed in various ways, depending mainly on the kind of analysis required:

(a) Recording only first contacts, and calculating the mean number of first contacts per hundred quadrats, the percentage cover (p).

(b) Recording all contacts through the entire depth of the stand, and calculating the mean number of contacts per hundred quadrats, the relative frequency (r).

(c) Recording contacts on crowns only, thus expressing the basal area contribution of each species.

Comparative studies with other techniques have illustrated both the consistency and rapidity of point quadrat analysis (9, 11, 15, 20, 21, 24, 26, 35, 41, 44, 46, 50, 52, 57, 60, 63, 66, 67, 68, 69, 81, 82, 88). Recording p is a rapid and easy method for determining dominant species when only one growth form predominates in an association. If, for instance, erect and prostrate species exist in an association, p leads to a bias in favour of the taller species, which can be overcome by recording first contacts with each species in the association. Recording r makes yield and leaf area correlation possible (see later sections) and usually gives botanical analysis values similar to those from yield estimates. Such a value (r) would be the most useful where estimates of growth are required. The ratio r/p yields the mean cover repetition where any cover exists (31). Plant form affects the accuracy of measurement (1, 31), compact plants with a small projected area having a much lower probability of point-plant contact, and hence tend to be underestimated by both p and r. Comparisons involving stolaniferous and crown forming plants can also offer interpretation problems. Goodall (32) has derived a method of obtaining more reliable data for cover repetition in tussock centres, where this value is particularly high.

Changes in botanical composition and population with time would be more suitably studied with basal area records, as may regeneration studies. Basal area records do not have the disadvantage of being influenced by the amount of growth present (58), which may depend on short term climatic conditions, and not necessarily be related to long term trends in ground cover contribution. The technique is capable of refinement to a micro-scale, particularly by use of cross hairs on optical instruments. An example is the estimation of botanical composition of rumen contents (29).

FLORISTIC PATTERN

Association of species

Providing a known systematic placement and recording procedure is followed, the relation of any one quadrat record to others in proximity to it can be analysed. Thus any pattern existing in the association of one species with any other can be determined. The treatment of data for association analysis can be undertaken in various ways (10, 30, 33, 34, 43, 53, 70, 83, 84, 85, 90), having different ecological merits, but suffice it to say here that systematic point quadrat sampling forms an ideal basis for such interpretations.

Dispersion

The variation or dispersion of foliage, particularly in the horizontal plane, is often important in considerations of light utilization (72, 74, 78). Regularity of arrangement often being associated with high productivity through higher efficiencies of light interception. The variation of point quadrat contacts can be analysed by either poisson probability or relative variance index (72, 74). In the former analysis, the relative frequency of 1, 2, 3 ...n contacts per quadrat are plotted against the number of contacts per quadrat. For foliage distributed randomly points fall on a vertical line, while a negative slope indicates a regular arrangement, and a positive slope clumping.

The relative variance can be defined as the ratio of the variance of the point contact data to the mean number of contacts per quadrat. This index is equal to one for random arrangem nts, less than one for regular dispersion and greater than one for clumped foliage. The more marked the degree of regularity or clumping, the greater the deviation from unity, which can be interpreted statistically (34, 43). Warren Wilson (72) has shown a negative association between the foliage of ryegrass and that of other species. Presumably through the effects of competition, the foliage of these other species occurs where there are gaps in the dominant ryegrass foliage.

Orientation

The leaves of some species orient themselves in relation to some compass direction, presumably in response to environmental variables such as incident light or wind. The contact frequency of horizontal quadrats can be used to quantify such orientation, by virtue of the fact that contacts will be at a maximum when normal to the leaf surface, and at a minimum when at right angles, that is parallel to the leaf blade. The relation of these maxima and minima to compass direction quantifies orientation.

YIELD

The point technique depends on surface contacts, and can take no account of density (27, 62). If an assumption can be made that densities of each surface contact are similar, good correlations with weight estimates can be obtained (40). On the other hand correction or weighting factors can be applied, with the knowledge that these frequency-weight correlations change with growth, height, season, species and environment (11, 12, 23, 35, 37, 40, 46, 58, 63, 65, 69), to achieve satisfactory yield estimates. Furthermore, point sampling may offer the advantage of non destructive in situ estimates (37, 40, 65).

LEAF AREA

The mean number of leaf contacts per quadrat (f_β) represents the area projected in the direction of the quadrat (β). The actual leaf area index (80) of the stand (F) will be related to the projected leaf area index (F_β) by the angles of leaf (α) and quadrat (β), both being measured with reference to the horizontal (73, 75). The mean number of contacts per quadrat is related to the projected leaf area index by the relationship:

$$F_\beta = f_\beta \sin \beta \qquad \text{(I)}$$

The relative frequency, r, defined previously, is given by the relationship:

$$r = 100 f_\beta \qquad \text{(II)}$$

The relation of f_β to F with variation in α and β can be defined by equations I, III, and IV (73).

$$\frac{F_\beta}{F \sin\beta} = \cos\alpha \qquad \text{(III)}$$

$$(\text{where } \alpha \lesseqgtr \beta)$$

$$\frac{F_\beta}{F \sin \beta} = \cos \alpha \left(1 + \frac{2}{\pi} (\tan \Theta - \Theta) \right) \qquad \text{(IV)}$$

(where $\alpha > \beta$, and

$$\Theta = \cos^{-1} (\tan \beta \; / \tan \alpha))$$

From such theoretical calculations it is possible to study the effect of various quadrat angles and combinations on the error of F due to particular α values. Equations of varying reliability can be obtained (Table I), introducing constants to bring the ratio $f\beta/F$ as close as possible to unity. In practice α is distributed over a wide range (38, 54) limiting the error due to a particular leaf angle. Duncan et al (25) present the relationship of this ratio to α and β in tabular form. Selection of optimal formulae is discussed in a later section on statistical strategy. Philip (54) has developed a seven angle formula for F, while Miller (47), using an alternative formula for average foliage density, has calculated different coefficients for this seven angle formula.

Using the intrinsic differences between leaf and stem shapes, Philip (56) has calculated more accurate formulae for the density of stem like organs (S).

$$\text{Foliage Density} = F + S \qquad \text{(V)}$$

Interpretations of foliage density distribution for single plants and **row** crops are given by Warren Wilson (77) and Philip (55).

LEAF AND STEM ANGLE

The mean leaf angle ($\bar{\alpha}$) can be calculated from mean contact frequencies for any two quadrat angles (71, 75).

$$\tan \bar{\alpha} = \frac{\pi}{2} \cdot \frac{f_{\beta_1}}{f_{\beta_2}} \qquad \text{(VI)}$$

The ratio $f_0 \,/\, f_{90}$ provides the most sensitive measure of $\bar{\alpha}$, changing in magnitude more than any other ratio, other ratios also having the disadvantage of being constant for all values of α less than the shallower quadrat inclination (75).

Mean axial stem angle is given by the relationship:

$$\frac{E(\cos \bar{y})}{\cos \bar{y}} = \frac{\pi}{2} \cdot \frac{f_{\beta_1}}{f_{\beta_2}} \qquad \text{(VII)}$$

where f_{β_1} and f_{β_2} are mean stem contact frequencies, and E is Legendre's complete elliptic integral of the second kind.

Perhaps of more fundamental importance, particularly to canopy structure and productivity models (25, 49), is the distribution of α between 0° and 90°. Leaf angle has an important bearing on light penetration and distribution over leaf surfaces (74). Philip (54) has devised a method of calculating such information from multiple angle (seven) point quadrat data. He introduces the term foliage angle density function $g(\alpha)$, defined as the contribution to density due to foliage inclined to the horizontal at angles between α_0 and $\alpha + d\alpha$ being $g(\alpha_0)d\alpha$. The foliage density is then given by:

$$F = \int_0^{\frac{\pi}{2}} g(\alpha)d\alpha \qquad \text{(VIII)}$$

Philip (54) used a smoothing technique (fitting an equation to resource random variation) for the contact frequency - quadrat angle data, and calculated $g(\alpha)$ from the equation:

$$g(\alpha) = \tan\alpha \ \sec^3\alpha \int^{\frac{\pi}{2}} \frac{3\cos^2\beta\sin\beta(f(\beta) + f''(\beta)) - \cos^3\beta\,(f'(\beta) + f'''(\beta))}{(\tan^2\beta - \tan^2\alpha)^{\frac{1}{2}}}\,d\beta$$

(The primes denote differentiation with respect to β) (IX)

The foliage angle density function is then plotted against leaf angle to obtain the distribution curve. The approximate Fourier analysis used by Philip is not well suited to give accurate estimates when the mode of $g(\alpha)$ is close to $\alpha = 0$, and alternatives are suggested by Philip (54). Miller (47) proposed a formula for the average foliage density

$$F \int_0^{\frac{\pi}{2}} f(\beta) \cos\beta \ d\beta \qquad \text{(X)}$$

which offers the advantage of not estimating the third derivative from f in equation IX, and avoids the estimation of $g(\alpha)$ altogether.

CANOPY PROFILES

Recording contacts made by point quadrats within horizontal layers of limited depth means that profiles of leaf area, stem density and their angular distribution can be constructed (39, 62, 71, 72, 77, 78, 79). Such profiles of canopy structure are important in the interpretation of environmental profiles and productivity models since the foliage provides sources and sinks for fluxes of water vapour, carbon dioxide, oxygen and radiation.

LIGHT UTILIZATION

Interception and Penetration

The path along which a point quadrat moves can be used to simulate the entry of a ray of sunlight or skylight into the canopy (78). The first contact with foliage made by the quadrat corresponds to light interception, and expressing the data as first contacts per 100 quadrats (p) represents per cent light interception. Conversely, light penetration is given by gap per 100 quadrats (1 - p). Such interpretations can be made either directly from observed first contact data, or from equations using the relative frequency (r), which assume random foliage dispersion (76, 78).

cover $p = 1 - e^{-r}$ interception (XI)

gap $1 - p = e^{-r}$ penetration (XII)

The effect of variable foliage area F (or more correctly FD defined earlier V), foliage angle (α), and angle of entry (β) on light interception can be theoretically obtained from equations I, II, III, IV (73, 76, 78). These calculations (78) show that gap decreases with increasing F, except for very erect foliage, and that gap does not change with increasing β if $\alpha \leqslant \beta$, but falls with β if $\alpha > \beta$. The weakness of such theoretical calculations is related to non-random foliage dispersion, and the variable distribution of foliage angle. Nevertheless, estimates of gap from r and p have shown close agreement in variable canopy types (39, 78).

Extinction Coefficient

Light attenuation within crop canopies is commonly claimed to follow Beer's Law (3, 8, 48);

$I / I_0 = e^{-KF}$ (XIII)

where I_0 = light intensity above the canopy

I = light intensity under a foliage area index of F

K = extinction coefficient

Anderson (6) has devised a formula for K in terms of point quadrat measurements;

$K = F\beta / (F \sin \beta)$ (XIV)

Equations III and IV linking $F\beta$ and F can be used to define K for any value of α, β and F (73). This extinction coefficient varies with leaf angles, sun angles, proportions of direct and diffuse light, and the optical properties of leaves (6, 74). The ratio $F\beta / F$ is a measure of the shadow cast by a leaf, or theprojected area exposed to intercept light, and will be related to F through α and β (Equations III and IV) (25). The light intensity over the surface will decrease as $I_0 \cos \alpha$, (I_0 being the light intensity at the site) and together with a knowledge of the amount of leaf present and its photosynthesis - light intensity response curve, estimates of canopy photosynthesis (25) can be made.

Diffuse and Direct Site Factors

Satisfactory estimates of canopy photosynthesis require a detailed knowledge of light penetration and scattering (8, 25, 49). Anderson (4, 5) analysed light penetration in canopies in terms of direct and diffuse site factors:

$I_0 = a + x\,D + y\,I$ (XV)

where I_0 = total irradiance at the site

a = statistically non significant elevation constant

x and y, the partial regression coefficients, are estimates of the diffuse and direct site factors respectively

D is the diffuse and I the direct irradiance in the open.

Estimates of the daily direct site factor can be obtained by plotting gap against time of day and taking the area under the curve. The pattern of solar elevation with time of day being assumed prior knowledge. Hourly variations in the direct site factor are given by gap at the appropriate quadrat angle.

Diffuse site factors are obtained by plotting gap against quadrat angle β, and estimating the area under the curve. If a sky is of non uniform brightness (4, 5, 25) then this part ($\equiv \beta$ quadrat angle) can be weighted accordingly. Daily site factors appear to be relatively constant (4, 5, 8), though hourly variation is considerable. Conventional measurements (5, 8) of this variation are difficult to make, and point quadrat interpretation offers a viable alternative.

Sunlit Leaf Area Index

Estimates of leaf area which is sunlit and shaded are used in production models (25, 49) and can be estimated from point quadrat first contact records (79).

Complete cover:

$*F = F / f_\beta$ (XVI)

where $*F$ = sunlit leaf area index

Incomplete cover:

$*F = F\,(1 - e^{-f\,\beta}) / f_\beta$ (XVII)

INSTRUMENTATION

The determination of botanical composition was commonly made from frames of ten points, several of which are described in the literature (14, 15, 18, 20, 27, 36, 46, 50, 89). Multiple angle analysis for light utilisation interpretation requires more sophisticated instrumentation (38, 76). The cross hairs of optical instruments have been successfully used by some authors (2, 16, 29, 87).

STATISTICAL STRATEGY

Number of Quadrats

The accuracy of any point quadrat determination will depend on the number of contacts established (56). Assuming random distribution of foliage, the per cent relative standard error (E) will be related to the number of contacts (N) by the linear relationship (56).

$$\log E = \log a + b \log N \qquad \text{(XVIII)}$$

where $\log a = 4.605$

and $b = -0.5$

The collection of point quadrat data should then be planned on a fixed number of contacts, not on set numbers of quadrats.

The type of record to be made (eg. p or r) will obviously influence mean contact number per quadrat and hence total quadrats required. Large variations in quadrat numbers for acceptable accuracies result from variable plant and association type, affecting mean contacts per quadrat (1, 22, 28, 31, 32, 41, 60, 63, 81, 82). The variation of contact number from layer to layer in a profile, may mean that comparisons involve data of varying accuracies. In this case height intervals may be selected after sampling so that contacts are distributed evenly between layers, avoiding the problems outlined by Philip (56). A similar problem exists in botanical analysis, where minor species in an association are often overestimated because of the small number of contacts established with them, (31, 42, 46). A decision must be made whether minor improvements in accuracy warrant the extra time and effort required to establish more contacts.

While it is impossible to answer the general question concerning the number of quadrats required without any prior knowledge of contact frequency, Warren Wilson (75) makes some obvious comments on strategy and Goodall (31) suggests that a sensible estimate can be made if the area under study is divided into small portions, and two points placed at random recorded within each portion. The variance between points of a pair will indicate roughly the number of points required for a given precision.

Standard Deviation of k points $= \sqrt{\frac{pq}{k}}$

where p = percentage cover, and q its complement,

q = 100 - p

With inclined quadrats equal numbers ought to be taken in various compass directions to avoid orientation bias, and problems with sloping or uneven ground are discussed by Warren Wilson (75).

Distribution of Quadrats

The distribution of quadrats in a sample area will depend considerably on the type of measurement required. Generally random distribution is satisfactory (14, 31), though where patterns and associations are being measured, some sort of organised sample placement is necessary (30, 31, 70). Fisser and Van Dyne (28) found the optimum sampling distribution to depend on growth form; random placement being significantly better on sod forming species, and systematic samples on bunch grasses, while for plant groups with high basal cover, either placement would suffice. Shockey et al (61) on a large scale land use survey concluded a systematic point sampling procedure to be over three times as efficient as random samples. Botanical composition estimates by early workers were often made with frames of ten pins, the figure ten being a rather arbitrary selection. Goodall (31) and Blackman (13) suggest this could be an uneconomical use of recording labour, leading to bias, since forsome plant types the probability of hitting a given species will vary less between the different sections of one frame than between the different positions of the frame. Kemp and Kemp (42) have estimated the number of locations, for differing numbers of pins per frame, that are required for a given precision. Until the time saved in making fewer observations offset the extra time needed for moving the apparatus no advantage can be gained. Use of set points on line traverses has been used effectively for establishing a sampling pattern, the distance between points on each transect and the distance between transects being geared to changes in vegetation to be measured (18, 28, 31, 60, 75, 82). Changes in vegetation with time are more accurately observed if the systematic point can be relocated from distant marker pegs (17, 31).

Selection of Quadrat Angle

Inclined pins were used in some early work on botanical composition (11, 67) and claimed to be more clearly visible and more accurate. Winkworth (86), however, found no such improved visibility of pins, and suggested that the increased accuracy was obtained through increased recording labour.

In the estimation of leaf area and stem densities inclined quadrats (73) and multiangle formulae (75) offer substantial advantages in improved accuracies. This arises from the decreased probability of quadrat angle coinciding with mean stem or leaf angle, and providing inaccurate low contact frequencies.

The choice of formulae should be based on the maximization of accuracy for a given amount of recording labour. Philip (56, see fig. 7) has linked these statistically and presents graphically the optimum efficiency for the use of one, two and three angle formulae. Where it is desired to estimate not only the foliage density, but also the mean foliage or axial angle, Philip (56) considers that the inclusion of quadrat angles 0^{o} and 90^{o} in a set of observations is as far as one should go in sacrificing the accuracy of density measurements in order to make the estimate of mean angle. Contact numbers for each angle of the formula should be in proportion to the respective coefficients of that formula. Where several angles are used both for the purposes of interpreting light penetration (6, 78, 79) and calculating foliage angle distribution (54) then equal distribution of contacts between angles is desirable.

Pin Size

The theoretical basis of point sampling is that they have no area. However, points used in vegetation sampling are made up of pins with finite area, which can constitute a source of error. The thicker the point or needle, the greater the overestimation of cover (11, 31, 41, 42, 72, 76). Obviously, care must be taken with instrument construction to avoid pin vibration and lateral movement. Warren Wilson (72, 76) suggested the use of finely tapered pins substantially minimized this error, which could be expressed mathematically as a percentage of true foliage area by the formula

$$\frac{100\ d}{l\ b}\ (d + l + b)$$

where d = diameter of pin

l = length of leaf in vertical projection

b = breadth of leaf in vertical projection

Error depends more on foliage area than shape, and a correction factor can be used for quadrat thickness in estimates of percent composition by multiplying r by $\frac{l\ b}{(l+d)(b+d)}$ (76)

Observer Variation

The technique involves making positive or negative decisions on point-plant contacts. Foliage movement, wilting, orientation changes, instrument vibrations, fatigue effects and intrinsic differences between observers in what constitutes a point-plant contact may lead to bias. It is not surprising then that the technique is subjective and open to considerable differences between observers (22, 31, 51). This bias can be avoided by ensuring each observer used establishes an equal number of contacts in each treatment.

Data Collection Time

Usually leaf area profile measurements are the slowest, particularly where various quadrat angles are used. Over 500 contacts can be established in a day with swards of leaf area index 6 - 8, this dropping by half for leaf area index values about 3. In this case the time spent in moving quadrat positions constitutes a large proportion of the sampling time. Undoubtedly the biggest restraint on more use being made of the point quadrat technique for canopy structure and light penetration interpretations, lies in the long time and tedium required to establish sufficient contacts for acceptable accuracy. Furthermore, where hourly changes in light penetration characteristics are of interest, canopy structure data collected over 3 - 5 days must have doubtful validity.

Where floristic composition and pattern is of interest, the procedure is very much quicker and efficient compared to other techniques (14, 20, 21, 22, 41, 60, 61, 64, 67), possibly reaching 2000 contacts in a day, though this again depends considerably on association type and density (15, 22).

TABLE I

A summary of density formulae appearing in the literature

EQUATION	ERROR	SOURCE
$F = F_{90} \sec \alpha$		71
$F = \sqrt{\frac{\pi^2}{4} F_0^2 + F_{90}^2}$		71
$F = F_{90}\sqrt{1 + \tan^2 \alpha}$		71
$F = f_{45}$	± 36%	73
$F = f_{29}$	± 15%	73
$F = 1.1\ f_{32.5}$	± 10%	73
$F = 2.05\ F_{32.5}$	± 10%	73
$S = 2.00\ F_{36.1}$	± 3%	56
$S = 1.96\ F_{32.5}$	± 5%	56
$F = F_{13} + F_{52}$	± 2.5%	56
$F = 0.23\ f_{13} + 0.78\ f_{52}$	± 2.5%	75
$S = 0.996\ (F_{13} + F_{52})$	± 0.9%	56
$S = 0.999\ (1.2\ F_{15} + 0.8\ F_{60})$	± 0.9%	56
$F = F_0 + F_{90}$	± 29%	56
$F = 1.30\ F_0 + 0.83\ F_{90}$	± 16%	56
$S = 1.48\ F_0 + 0.54\ F_{90}$	± 5.5%	56
$F = 0.43\ F_0 + 1.30\ F_{32.5} + 0.28\ F_{90}$	± 3%	56
$F = 0.43\ f_0 + 0.70\ f_{32.5} + 0.28\ f_{90}$	± 3%	75
$F = 0.089\ f_8 + 0.462\ f_{32.5} + 0.453\ f_{65}$	± 1%	75
$F = 0.64\ F_8 + 0.86\ F_{32.5} + 0.55\ F_{65}$	± 1%	56
$S = 0.55\ F_0 + 1.24\ F_{36.1} + 0.21\ F_{90}$	± 1.3%	56
$S = 0.29\ F_0 + 1.49\ F_{32.5} + 0.22\ F_{90}$	± 1.5%	56

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BIBLIOGRAPHY

1. Aberdeen, J.E.C. The effect of quadrat size, plant size, and plant distribution on frequency estimates in plant ecology. Aust. J. Bot. 1958, 6, 47-58.
2. Alberda, T. Dry matter production and light interception of crop surfaces. 4. Maximum herbage production as compared with predicted values. Neth. J. Agric. Sci. 1968, 16, 142-153.
3. Anderson, M.C. Light relations of terrestrial plant communities and their measurement Biol. Rev. Cambridge Phil. Soc. 1964, 39, 425-486.
4. --- Studies of the woodland light climate. 1. The photographic computation of light conditions. J. Ecol. 1964, 52, 27-41.
5. --- Some problems of simple characterization of the light climate in plant communities. In: Bainbridge, R.; Evans, G.C.; Rackman, O. (Eds) Light as an Ecological Factor. Symp. Brit. Ecol. Soc. 1966, 6, 77-90.
6. --- Stand structure and light penetration. 2. A theoretical analysis. J. Appl. Ecol. 1966, 3, 41-54.
7. --- A comparison of two theories of scattering of radiation in crops. Agr. Meteorol. 1969, 6, 399-405.
8. --- Interpreting the fraction of solar radiation available in forest. Agr. Meteorol. 1970, 7, 19-28.
9. Anonymous. Point sampling. U.S.D.A. Misc. Pub. 1962, 940, 26-27.
10. Archibald, E.E.A. The specific character of plant communities. 2. A quantitative approach. J. Ecol. 1949, 37, 274-288.
11. Arny, A.C.; Schmid, A.R. A study of the inclined point quadrat method of botanical analysis of pasture mixtures. J. Am. Soc. Agron. 1942, 34, 238-247.
12. Arny A.C. Alfalfa and grass percentage determinations with the inclined point quadrat apparatus at different stages of development of the mixtures. J. Am. Soc. Agron. 1944, 36, 996-998.
13. Blackman, G.E. Statistical and ecological studies on the distribution of species in grassland associations. Ann. Bot. 1935, 49, 749-777.
14. Brown, D. Methods of surveying and measuring vegetation. Bull. 42, Commonwealth Bur. Past. Fld. Crops. Farnham Royal: Commonwealth Agric. Bur. 1954, pp. 233.
15. Brun, J.M.; Box, T.W. A comparison of line intercepts and random point frames for sampling desert shrub vegetation. J. Range Mgmt. 1963, 16, 21-25.
16. Burzlaff, D.F. The focal point technique of vegetation inventory. J. Range Mgmt. 1966, 19, 222-223.

17. Cain, S.A.; Castro,G.M. de O. Manual of Vegetation Analysis. New York: Harper 1959, 198-201.

18. Charnrad, A.D.; Box, W.T. A point frame for sampling rumen contents. J. Wildlife Mgmt. 1964, 28, 473-477.

19. Cockayne, L. Tussock Grassland Investigation in New Zealand. In: Tansley, A.C.; Chipp, T.F. (Eds) Aims and Methods in the Study of Vegetation. 1926, 349-372.

20. Cook, C.W.; Box, T.W. A comparison of the loop and point methods of analysing vegetation. J. Range Mgmt. 1961, 14, 22-27.

21. Cottam, G. A point method for making rapid surveys of woodlands. Bull. Ecol. Soc. Am. 1947, 28, 60.

22. Crocker, R.L.; Treer, N.S. Survey methods in grassland ecology. J.Br. Grassld. Soc. 1948, 3, 1 - 26.

23. Dirven, J.G.P.; Hoogers, B.J.; De Vries, D.M. Interaction between frequency dominance and dry weight percentages of species in grassland vegetation. Neth. J. Agric. Sci. 1969, 17, 161-167.

24. Drew, W.B. Studies on the use of the point quadrat method of botanical analysis of mixed pasture vegetation. J. Agric. Res. 1944, 69, 287-297.

25. Duncan, W.G.; Loomis, R.S.; Williams, W.A.; Hanau, R. A model for simulating photosynthesis in plant communities. Hilgardia, 1967, 38, 181-205.

26. Ellison, L. A comparison of methods of quadrating short grass vegetation. J. Agric. Res. 1942, 62, 595-613.

27. Fenton, E.W. The point quadrat method. Agric. Prog. 1933, 10, 238-242.

28. Fisser, H.G.; Van Dyne, G.M. Influence of number and spacing of points on accuracy and precision of basal cover estimates. J. Range Mgmt. 1966, 19, 205-211.

29. Galt, H.D.; Ogden, P.R.; Ehrenreich, J.H.; Theurer, B.; Martin, S.C. Estimating botanical composition of forage samples from fistulated steers by a microscope point method. J. Range Mgmt. 1968, 21, 397-401.

30. Gilbert, N.; Wells, T.C.E. Analysis of quadrat data. J. Ecol. 1966, 54, 675-685.

31. Goodall, D.W. Some considerations in the use of point quadrats for the analysis of vegetation. Aust. J. Sci. Res. 1952, 35, 1-41.

32. --- Point quadrat methods for the analysis of vegetation. The treatment of data for tussock grasses. Aust. J. Bot. 1953, 1, 457-461.

33. --- Plot-less tests for interspecific association. J. Ecol. 1965, 53, 197-201.

34. Greig-Smith, P. Quantitative plant ecology. 1964, pp 198. London: Butterworths.

35. Hanson, H.C. A comparison of methods of botanical analysis of the native prarie in western North Dakota. J. Agric. Res. 1934, 49, 815-842.

36. Heady, H.F.; Rader, L. Modifications of the point frame. J. Range Mgmt. 1958, 11, 95-96.

37. Heady, H.F.; Van Dyne, G.M. Prediction of weight composition from point samples of clipped herbage. J. Range Mgmt. 1965, 18, 144-148.

38. Heslehurst, M.R. A point quadrat instrument for use in high vegetation. In: Instrumentation for plant environment measurements. p.1. CSIRO Aspendale Conf. Soc. Instrum. Tech. Aust., Sept. 1966.

39. Heslehurst, M.R. Studies on the productivity of tropical pasture plants. 3. Stand structure, light penetration, and photosynthesis in field swards of setaria and green leaf desmodium. Aust. J. Agric. Res. 1971, 22,(6), (in press).

40. Hughes, E.E. Estimating herbage production using inclined point frame. J. Range Mgmt. 1962, 15, 323-325.

41. Johnston, A. A comparison of the line interception, vertical point quadrat, and loop methods as used in measuring basal area of grassland vegetation. Can. J. Plt. Sci. 1957, 37, 34-42.

42. Kemp, C.D.; Kemp, A.W. Analysis of point quadrat data. Aust. J. Bot. 1956, 4, 167-174.

43. Kershaw, K.A. Quantitative and dynamic ecology. 1964. pp. 183, London: Edward Arnold.

44. Kim, D.A. Studies on the use of point quadrat methods. 1. A comparison of the vertical point quadrat methods in analysis of pasture mixtures. J. Jap. Soc. Grassld. Sci. 1964, 10, 13-17.

45. Levy, E.B. Technique employed in Grassland Research in New Zealand. Bull. 11 Imp. Bur. Plant Gen. 1933, Herbage Plants.

46. Levy E.B.; Madden, E.A. The point method of pasture analysis. N.Z. J. Agric. 1933, 46, 267-279.

47. Miller, J.B. A formula for average foliage density. Aust. J. Bot. 1967, 15, 141-144.

48. Monsi, M.; Sacki, T. Uber den lichtfaktor in den pflanzengesellschaften und seine bedeutung fur die staffproduktion. Jap. J. Bot. 1953, 14, 22-53.

49. Monteith, J.L. Light distribution and photosynthesis in field crops. Ann. Bot. 1965, 29, 17-37.

50. Mountier, N.S.; Radcliffe, J.E. Problems in measuring pasture composition in the field. 3. An evaluation of point analysis, dry weight analysis and tiller analysis. N.Z. J. Bot. 1964, 2, 131-142.

51. ---; --- Problems in measuring pasture composition in the field. 4. Observer variation with the point method. N.Z. J. Bot. 1965, 3, 243-252.

52. Nauch, Z.; Landau, N.; Putter, J.; Toledando, D. A comparison of several methods of determining the botanical composition of Mediterranean grassland. Israel J. Agric. Res. 1963, 13, 79-91.

53. Orlaci, L. Geometric models in ecology. 1. The theory and application of some ordination methods. J. Ecol. 1966, 54, 193-215.

54. Philip, J.R. The distribution of foliage density with foliage angle estimated from inclined point quadrat observations. Aust. J. Bot. 1965, 13, 357-366.

55. Philip, J.R. The distribution of foliage density on single plants. Aust J. Bot. 1965, 13, 411-418.

56. Philip, J.R. The use of point quadrats with special reference to stem like organs. Aust. J. Bot. 1966, 14, 105-125.

57. Radcliffe, J.E.; Mountier, N.S. Problems in measuring pasture composition in the field. 1. Discussion of general problems and some considerations of the point method. N.Z. J. Bot. 1964, 2, 90-97.

58. ---; --- Problems in measuring pasture composition in the field. 2. The effect of vegetation height using the point method. N.Z. J. Bot. 1964, 2, 98-105.

59. Reid, D. Studies on the cutting management of grass clover swards. 1. The effect of varying the closeness of cutting on the yields from an established clover sward. J. Agric. Sci. 1959, 53, 299-312.

60. Robinson, P. The estimation of ground cover by the point quadrat method. Ann. Bot. 1955, 19, 59-66.

61. Shockey, W.R.; De Coursey, D.G. Point sampling of land use in the Washita Basin, Oklahoma. U.S. Agr. Res. Ser. 1969, rev. 44, pp 8.

62. Spedding, C.R.W.; Large, R.V. A point quadrat method for the description of pasture in terms of height and density. J. Brit. Grassld. Soc. 1957, 12, 229-234.

63. Sprague, V.G.; Myers W.M. A comparative study of methods for determining yields of Kentucky blue grass and white clover when grown in association. J. Am. Soc. Agron. 1945, 37, 370-377.

64. Stewart, G.; Hutchings, S.S. The point observation plot method of vegetation survey. J. Am. Soc. Agron. 1936, 28, 714-722.

65. Teare, I.D.; Mott, G.O. Estimating forage yields in situ. Crop Sci. 1965, 5, 311-313.

66. Thomas, W.D.; Lazenby, A. Some comparisons of inclined point quadrat on airflow planimeter methods for measuring leaf area index of grass swards. J. Brit. Grassld. Soc. 1968, 23, 268-273.

67. Tinney, F.W.; Aamodt, O.S.; Ahlgren, H.L. Preliminary report of a study of methods used in botanical analysis of pasture swards. J. Am. Soc. Agron. 1937, 29, 835-840.

68. Trier, N.S.; Crocker, R.S. The grasslands of Southeast South Australia in relation to climate, soils and developmental history. J. Brit. Grassld. Soc. 1951, 6, 29-80.

69. Van Keuren, R.W.; Ahlgren, H.L. A statistical study of several methods used in determining the botanical composition of a sward. 1. A study of established pastures. Agron. J. 1957, 49, 532-536.

70. Von Bronembsen, H.H. The logarithmic series applied to point samples drawn from natural pastures. Proc. 10th int. Grassld. Congr., Helsinki, 1966, 1966, 913-916.

71. Warren Wilson, J. Analysis of the spatial distribution of foliage by two dimensional point quadrats. New Phytol. 1959, 58, 92-101.

72. --- Analysis of the distribution of foliage area in grassland. In: J.D. Ivins (Ed) The measurement of Grassland Productivity. Proceedings of the Easter School in Agricultural Science, University of Nottingham, 1959. London: Butterworth & Co., 1959, pp. 51-61.

73. --- Inclined point quadrats. New Phytol. 1960, 59, 1-8.

74. --- The influence of spatial arrangement of foliage area on light interception and pasture growth. Proc. 8th int. Grassld. Congr., Reading, 1960, 1960, pp. 275-279.

75. --- Estimation of foliage denseness and foliage angle by inclined point quadrats. Aust. J. Bot. 1963, 11, 95-105.

76. --- Errors resulting from thickness of point quadrats. Aust. J. Bot. 1963, 11, 178-188.

77. --- Point quadrat analysis of foliage distribution for plants growing singly or in rows. Aust. J. Bot. 1965, 13, 405-409.

78. --- Stand structure and light penetration. 1. Analysis by point quadrats. J. appl. Ecol. 1965, 2, 383-390.

79. --- Stand structure and light penetration. 3. Sunlit foliage area. J. appl. Ecol., 1967, 4, 159-165.

80. Watson, D.J. Leaf growth in relation to crop yield. In: F.L. Milthorpe (Ed) The Growth of Leaves. Proceedings of the Easter School in Agricultural Science, University of Nottingham, 1956. London: Butterworths & Co. 1956, pp. 178-191.

81. West, O. An investigation of the methods of botanical analysis of pasture. S. Afr. J. Sci. 1937, 33, 501-559.

82. Whitman, W.C.; Siggeirsson, E.I. Comparison of line interception and point contact methods for mixed grass range vegetation. Ecology, 1954, 35, 431-436.

83. Williams, R.M. The variance of themean of systematic samples. Biometrica, 1956, 43, 137-148.

84. Williams, W.T.; Lambert, J.M. Multivariate methods in plant ecology. 1. Association analysis in plant communities. J. Ecol. 1959, 47, 83-101.

85. ---; --- Multivariate methods in plant ecology. 2. The use of an electronic digital computer for association analysis. J. Ecol. 1960, 48, 689-710.

86. Winkworth, R.E. The use of point quadrats for the analysis of heathland. Aust. J. Bot. 1955, 3, 68-81.

87. ---; Goodall, D.W. A crosswire sighting tube for point quadrat analysis. Ecology, 1962, 43, 342-343.

88. ---; Perry, R.A.; Rosetti, C.O. A comparison of methods of estimating plant cover in an arid grassland community. *J. Range Mgmt.* 1962, *15*, 194-196.

89. Woodall, S.R.J.; Boorman, L.A. A light sturdy inexpensive point quadrat frame. *Ecology*, 1966, *47*, 870-871.

90. Yarranton, G.A. A plotless method of sampling vegetation. *J. Ecol.* 1966, *54*, 229-237.

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