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AN EVALUATION OF EIGHT METHODS OF BOTANICAL ANALYSIS ON GRASSLANDS IN RHODESIA

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INTRODUCTION

Botanical analysis techniques suitable for use in grassland research have been developed and evaluated largely in the temperate regions of the world. The grassland vegetation in the savanna regions of Rhodesia differs greatly from natural grassland in temperate regions and there is a need to evaluate methods under local conditions.

This study was designed to evaluate eight methods of vegetation sampling on the basis of precision, information content, operator variability and efficiency (information gained for time spent). The trial involved three methods of estimating basal cover, namely the line intercept, the wheel-point method of Tidmarsh & Havenga (1955), and the variable plot method (Hyder & Sneva 1960); three methods of estimating density, namely quadrat-counting, the point-centered-quarter (PCQ) method (Dix 1961; Heyting 1968), and the angle order method (Laycock 1965); species frequency by quadrat; and the dry-weight-rank (DWR) method of 't Mannetje & Haydock (1963).

STUDY AREA AND METHODS

The methods were evaluated on two sites located on the Matopos Research Station, in the south-western part of Rhodesia. The area as a whole falls into the *Acacia* thornveld, as broadly classified by Wild & Fernandes (1967). On a smaller scale it is very heterogeneous and the particular sites selected occur in two of the most important vegetation types. The first site (Site 1) is on sandy soils derived from granite and the dominant species are the perennial bunch grasses *Hyperthelia dissoluta*, *Heteropogon contortus*, *Loudetia simplex* and *Hyparrhenia filipendula*. The second site (Site 2) is on red clay soils derived from basement schists and the dominant species are *Themeda triandra* and *Cymbopogon plurinodis*. In their natural state both types are dominated by woody vegetation, and the sites have been kept free of trees and scrub by hand-clearing and occasional burning.

Apart from representing different vegetation types, the sites were selected so as to encounter different sampling conditions. Site 1 had been burned the previous year and there was very little litter or old dead grass. On Site 2 the basal cover was higher, there were fewer grass species and because the area had been only lightly grazed and had not been burned for a number of years, there were considerable amounts of litter and old dead material.

Each site was laid out as a 2-ac rectangle and divided into fifteen sub-plots. The methods were tested by three different teams, each consisting of an operator and a recorder. In all but the wheel-point method, sample sites were located at random in each of the sub-plots. All three operators used the same sample sites within sub-plots. The time taken to apply each method was recorded to the nearest minute.

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Basal cover estimates

Rooted, dead material was recorded where the methods permitted it.

(1) *Line intercept*

A 10 m length of thin 60 lb breaking strain fishing wire was stretched tightly between two pegs, as close as possible to the surface of the soil. The operator stood astride the line and indicated to the recorder which plants and portions of plants to measure. Only rooted plant material directly beneath the line was recorded. Distances less than $\frac{1}{2}$ cm were measured to the nearest millimetre and those greater than $\frac{1}{2}$ cm to the nearest $\frac{1}{2}$ cm. Thirty 10 m lines were recorded in each site, with two randomly located lines in each sub-plot. Because the vegetation under a line was interfered with during measurement, and it was thought that successive measurements along the same line would be influenced by this interference, the operators used three different parallel lines spaced 1 m apart. It was assumed, as with all the other methods, that if the sample size proved insufficient to provide an acceptable confidence interval for the mean, it would at least be sufficient to allow an estimate of the required sample size.

(2) *Wheel-point*

There are a number of methods for estimating cover in which the percentage of 'strikes' as opposed to 'misses' in a series of placements of the point is recorded. The most common is the frame of ten points (Levy & Madden 1933), which has been criticized for increasing the variance of an estimate due to the points being closer than the mean plant area. Goodall (1952) estimated, for one particular site in Australia, that the frame of ten pins required about four times the number of random single points to obtain the same precision. Location of single points by the step-point approach is subject to excessive operator bias. The wheel-point method of Tidmarsh & Havenga (1955) involves regular spacing of points, but is free from the first two criticisms, and was adopted for this study. One drawback of the wheel-point is that it is not a point, and estimates are biased upwards.

The instrument was made according to the description of Tidmarsh & Havenga (1955) using $\frac{1}{4}$ in. diameter silver steel rods. The circumference of the wheel is 3 m and, as only one spoke was used as a point, this is the distance between points. For maximum speed of operation three people are required; one to pull the apparatus, one (the operator) to observe, and one to record. A total of 1875 points, 125 in each sub-plot, were recorded at each site.

(3) *Variable plot*

Hyder & Sneva (1960) describe a V-shaped gauge with a cover percentage factor of 1 for use in bunch grass vegetation. A similar gauge was used in this study for the determination of total basal cover. A thin steel peg which passed through a small hole very close to the point of the V was pressed into the ground. The gauge was pivoted in a full circle around this point. Any single rooted plant, the live material of which completely filled, or more than filled, the gauge, was recorded as 'in'. Where two species had grown together into a single tuft, the tuft was considered as a unit and if it filled the gauge each species was given a value of half. Rooted dead material was treated as a separate unit. Most of the tufts are of irregular shape and many have hollow centres, and it is therefore expected that the estimate of basal cover will be biased upwards. Thirty samples were recorded at each site, two in each sub-plot.

Density estimates

(4) *Quadrat counting*

The two factors that most influence the validity of density estimates by quadrat counting are the size and number of quadrats used. Because vegetation is in general contagiously distributed, the distribution of the resulting data will depend on the size of the quadrat, and to approximate to normality of the data the size should be such that there are more quadrats containing one individual than there are containing none (Greig-Smith 1964). Rice (1967) also recommends a size based on approximation of the normal curve. Greig-Smith (1964) and Kershaw (1964) conclude that, in general, the smallest possible size, practicable on other grounds, should be used. Shape is of some importance owing to its influence on edge effects and the fact that when elongated quadrats of a length greater than the unit of pattern are used, the standard error of the mean is reduced (Greig-Smith 1964).

A preliminary trial with nested quadrats showed a 20×40 cm quadrat to be the most suitable for the vegetation types in question. A total of ninety such quadrats were recorded in each site, six in each of the sub-plots.

A count was made of 150 quadrats on the basis of individual tillers, with a view to determining the most suitable vegetation unit. The numbers of tillers differed radically between species and the results had very little meaning. The individual tuft was therefore adopted as the unit. This procedure also allowed a direct comparison with the distance methods, which were performed on a tuft basis. The biggest problem involving individual tufts is that of fragmentation. All degrees occur, from small, compact individuals to old, broken ones that have separated into two or more smaller tufts. Criteria for recognition of individuals were defined by agreement between operators. More than half a tuft had to be inside a quadrat in order for that tuft to be counted.

(5) *Point-centred-quarter method (PCQ)*

Heyting (1968) has shown that the number of points required for a valid estimate of the relative density of a species rises sharply as the relative density decreases. He indicates that about 250 points give a meaningful result for the dominant species. In this study 250 points were recorded on Site 1 by locating at random ten points in each of twenty-five sub-plots. On Site 2, 240 points were recorded in fifteen sub-plots of sixteen points each.

Measurement to the nearest $\frac{1}{2}$ cm was made to the closest centre of an individual tuft in each quarter, regardless of size. The question of seedlings is particularly important in the PCQ technique, because only one individual is recorded in each quarter. In dense, temperate grassland it may not be a problem but in sub-tropical bunch grass savanna, where large spaces occur between tufts, the allocation of equal weight to a seedling 5 cm in height (albeit well-established) and to a robust tuft of fifty or more tillers some 200 cm high, may seriously reduce the value of the results obtained. Since a complete gradation of sizes occurs, and since different growth forms make it virtually impossible to use a specific height below which an individual may be ignored, it is necessary to take all individuals into account. In this study, individuals less than 5 cm in height were recorded as such.

(6) *Angle-order method*

The angle-order method is essentially similar to the PCQ except that the distance to the third closest centre of an individual tuft is measured. One hundred and fifty points were recorded at each site.

Frequency

In a randomly distributed population of a given species, a large number of quadrats of a size equal to the mean area of that species (i.e. the average number of individuals per quadrat = 1) will give a frequency value of about 63% (Curtis & McIntosh 1950). This is the most sensitive size of quadrat for detecting a change in that species at some future date. If the recorded frequency approaches 100% detection of any large increases that may occur will be limited to the maximum recordable value of 100%. A quadrat size that gives an initial estimate of 100% for any species can only detect a decrease in the abundance of that species. At the other end of the scale the reverse holds true. However, a quadrat size equal to the mean area of the most abundant species reduces the total number of species encountered, and may not give adequate information for indicator species. For maximum information concerning all species the most suitable size is that which results in a frequency of just less than 86% for the most abundant species (about twice the mean area of that species) (Hyder *et al.* 1963). A preliminary trial using nested quadrats indicated a 40 × 40 cm quadrat to be most suitable for the vegetation on Site 1 and one of 20 × 40 cm on Site 2.

Since frequency data is distributed binomially, the number of quadrats determines directly the confidence limits of values obtained. Fewer than 100 quadrats can only be used for characterizing simple stands of vegetation that differ markedly in species composition. A value of 50% recorded from 100 quadrats has a confidence interval of 40–60 at the 95% probability level (Snedecor 1956). In this study 150 quadrats were sampled at each site.

(8) *Dry-weight-rank method* (*DWR*)

This method, described by ’t Mannetje & Haydock (1963), gives an estimate of the percentage contribution of each species to the total yield of a pasture. In each of a number of quadrats an estimate is made as to which species occupy the first, second and third positions according to weight. The proportions of first, second and third ratings allocated to each species are then weighted by three previously determined constants, and the sum of these values, for each species, gives the percentage contribution of that species to the total weight of the sward. The constants used in this study are those derived by ’t Mannetje & Haydock (1963). Should it be shown that ranking is feasible in these vegetation types, then constants applicable to these conditions will have to be derived.

The method was applied at the same time as the frequency determinations, using seventy-five quadrats of 90 × 90 cm. In a number of sub-plots, the respective times taken to make the frequency and DWR estimates were recorded separately in order to determine the time taken by either method alone.

RESULTS

The sample size required to provide a 95% probability that the true value lies within 10% of the recorded mean was computed for each of the cover and density estimates using the formula $n = t^2_{0\cdot05} \cdot S^2/E^2$, where S^2 = the variance and E = the required confidence interval (in this case 20% of the mean). The required times and sample sizes have been determined on the basis of complete sub-plots.

Basal cover estimates

The wheel-point and variable plot techniques resulted, in general, in higher estimates than the line intercept (Table 1). In the wheel-point method this bias is mainly due to the fact that the spoke had a diameter of $\frac{1}{4}$ in. and was not a true point; in the variable plot method it is due to the irregular shape of tufts and to the inclusion of dead tuft centres.

Table. 1. *Total basal cover estimates obtained by* (1) *line intercept*, (2) *the wheel-point and* (3) *the variable plot methods at each of the two sites, with required times* (*in hours and minutes*) *and sample sizes for a* 20% *confidence interval* (P = 0·05)

	Operator 1			Operator 2			Operator 3		
Method	1	2	3	1	2	3	1	2	3
Site 1									
% live cover	3·99	5·76	4·83	4·31	4·96	5·23	6·10	4·91	5·80
% dead cover	2·23	2·19	0	2·34	2·45	0	1·79	1·44	0
Live and dead cover	6·22	7·95	4·83	6·65	7·46	5·23	7·89	6·35	5·80
Mean of untransformed sub-plot data	3·99	7·20	4·83	4·31	6·27	5·23	6·10	6·13	5·80
S.E. (sub-plot data)	0·23	0·74	0·40	0·21	0·53	0·41	0·39	0·46	0·28
No. of samples	30	1875	30	30	1875	30	30	1875	30
Required no.	11	2250	20	8	1625	20	13	1250	8
Time taken	8:44	3:35	1:45	8:17	3:10	1:15	9:27	4:20	2:00
Required time	3:13	4:18	1:10	2:13	2:45	0:50	4:06	2:54	0:32
Site 2									
% live cover	6·98	7·95	6·63	6·66	5·97	8·10	7·46	8·21	8·77
% dead cover	0·95	1·33	0	0·45	2·4	0	0·13	0·64	0
Live and dead cover	7·93	9·28	6·63	7·11	8·37	8·10	7·59	8·85	8·77
Mean of untransformed sub-plot data	6·98	9·93	6·63	6·66	8·13	8·10	7·46	10·27	8·77
S.E. (sub-plot data)	0·31	0·70	0·37	0·20	0·82	0·47	0·39	0·75	0·35
No. of samples	30	1875	30	30	1875	30	30	1875	30
Required no.	7	1125	10	3	2750	11	9	1250	5
Time taken	6:23	3:35	2:47	6:18	3:58	2:00	5:16	4:15	2:25
Required time	1:30	2:09	0:56	0:38	5:50	0:44	1:35	2:50	0:25

Within methods, estimates differed between operators by as much as 27%. The percentage cover recorded by operator 3 with the line intercept on Site 1 is higher than the values obtained by operators 1 and 2. The line intercept was the first method to be applied and the operators were at that time not practised in applying the definition of what was to be measured. In particular, differences in definition of the size of gap in a disintegrating tuft that warrants recognition as bare ground, resulted in the upward bias by operator 3. The same problem occurs with point methods of estimating cover, but in this trial the clarification of definitions was accomplished during the application of the line intercept, before the wheel-point method was tried. On Site 2, live cover estimates by the line intercept varied by only 10% between operators, whereas the other cover estimates varied by about 25%.

The variable plot has the disadvantage that it does not estimate dead cover unless an entire tuft, or large portion thereof, is dead. No dead matter was recorded by any operator on either site with this method. Furthermore, it does not allow for the measurement of anything other than bunch grasses.

In all but one instance, the time required to obtain equally precise estimates of cover was less for the line intercept than for the wheel-point. The averaged figures for times required by the three operators (Table 5) show a considerable increase for the wheel-point on Site 2. This was largely due to more difficult working conditions. In terms of operator time, the wheel-point is inherently less efficient than the line intercept, since in 2000 points only about 100 'strikes' are recorded, whereas with 30×10 m lines upwards of 500 individuals are intercepted, having a total length of about 15 m, with each measurement being to the nearest $\frac{1}{2}$ cm. Johnston (1957) found that for Canadian prairies the frame of points was more efficient than the line intercept, but his basal cover estimates varied between 10% and 44%. The variable plot technique requires far less time than the other two methods, but the results obtained are less informative.

The values for individual species show much the same order of importance for all three methods, and are valuable in this respect. However, in order to obtain a sufficiently accurate measure of any one species (and in particular the less abundant indicator species) such that a change of the order of 20% in the mean of that species may be detected at some other time, the number of samples required increases greatly. For example, whereas on Site 1, operator 1 required eleven lines to estimate total live basal cover to within 10% of the mean (Table 1), he required ninety lines for *Loudetia simplex* (the species with the highest basal cover) and 168 lines for *Heteropogon contortus* (third highest basal cover). If only one or two species are of interest, then the time taken to measure only those species may be sufficiently reduced to offset the increase in required sample size. If, however, in addition to an estimate of one or more individual species, total basal cover is also required, both the line intercept and wheel-point methods become very time-consuming.

Density estimates

The results of this trial support a previous belief that density as such is of very limited use in this kind of vegetation. Even when in good condition, a certain proportion of the tufts are always disintegrating to form two or more smaller tufts. Under severe grazing or other adverse treatment this process is accelerated and results in a larger number of smaller tufts with an overall decrease in basal cover. Both quadrat counting and PCQ approaches may therefore give rise to rather meaningless results, unless tuft size is somehow taken into account.

Required sample sizes for quadrat counts were computed from mean quadrat values per sub-plot, and for the PCQ methods from mean distance per sub-plot. The data were subsequently converted to tufts/m^2. Estimates of density from distance measurements (where r = point to plant distance) may be derived using $(\Sigma r/N)^2$ (Dix 1961), $\Sigma(4/\Sigma_1^4 r^2)/N$ (where four sectors are used)—Morisita's second estimate (Laycock 1965), and $\Sigma(1/r^2)\ /N$ —Morisita's first estimate. The last of these parameters can be used only where measurement is to second or higher order individuals, since it involves multiplication by $n-1$ (where n = order of individual).

For the first parameter, density from the PCQ data was estimated by $d = 1/(\Sigma r/N)^2$ and for the angle order data by $d = 225/64(\Sigma r/N)^2$ (M. Franklin, personal communication). Formulae and procedure for use of the other two parameters in transforming angle order data have been described elsewhere (Greig-Smith 1964; Laycock 1965). For PCQ data only the second of Morisita's formulae can be used. Estimates were made using all approaches and, on the basis of the quadrat count, density from the PCQ data was best estimated by $1/(\Sigma r/N)^2$ and from the angle order data by the procedure of Morisita, as outlined by Greig-Smith (1964). The quadrat count, although subject to variation, is a direct estimate of density and is used here as a basis on which to estimate the bias in the distance methods.

Both the PCQ and angle order techniques gave rapid estimates of mean distance and, if measurement is made to the centre of an individual, transformation of the distance measurements will give, in both cases, somewhat biased estimates of density (due to the distribution of the distance measurements). The extent of the bias is shown in Table 2. On Site 1, with the exception of the PCQ estimate by operator 3, both techniques overestimated the density. On Site 2 the PCQ gave an underestimate and the angle order approach gave an overestimate. On Site 1 the PCQ approach gave, in all cases, closer

Table 2. *Total density of tufts obtained by* (4) *quadrat counting,* (5) *the point-centred-quarter method and* (6) *the angle order method, at each of the two sites, with required times* (*in hours and minutes*) *and sample sizes for a* 20% *confidence interval* (P = 0·05)

	Operator 1			Operator 2			Operator 3		
Method	4	5	6	4	5	6	4	5	6
Site 1									
Density/m²	117·5	131·0	149·2	100·8	116·7	119·5	126·9	111·9	145·4
Mean of untransformed sub-plot data	56·4	8·7	17·8	48·4	9·1	18·0	60·9	9·4	16·2
S.E. (sub-plot data)	2·4	0·24	0·24	3·6	0·29	0·54	4·7	0·44	0·33
No. of samples	90	250	150	90	250	150	90	250	150
Required no.	24	20	10	60	30	20	60	40	20
Time taken	3:03	5:15	4:00	2:48	4:20	3:52	3:29	4:57	4:30
Required time	0:49	0:25	0:17	1:53	0:32	0:31	2:20	0:48	0:36
Site 2									
Density/m²	133·5	121·9	137·5	143·0	130·9	154·8	136·3	115·6	138·8
Mean of untransformed sub-plot data	10·7	9·0	17·2	11·4	8·7	16·1	10·9	9·3	17·1
S.E. (sub-plot data)	0·53	0·24	0·37	0·49	0·22	0·50	0·53	0·26	0·31
No. of samples	90	240	150	90	240	150	90	240	150
Required no.	30	32	10	24	16	20	24	32	10
Time taken	3:08	3:08	4:28	3:32	3:32	4:09	3:00	4:03	3:55
Required time	1:03	0:25	0:18	0:57	0:13	0:34	0:48	0:33	0:16

estimates to those obtained by tuft counting, although both distance methods were markedly biased. On Site 2 the angle order estimates were much closer to the tuft counts than were the PCQ estimates. Underestimation of density by distance methods is to be expected in aggregated populations owing to the non-linear relationship between distance and areas, and this effect has been observed elsewhere (Lyon 1968). No explanations can be offered for the overestimates obtained in this study. An important question here is whether the extent of the bias is sufficient to warrant the use of tuft counting, since the latter requires a two- to three-fold increase in time and is itself subject to operator bias.

In applying distance methods, the interpretation of mean distance needs careful consideration. Measurement to the nearest rooted piece of live material (Heyting 1968) results in a confused estimate of density and cover, because distances to plant centres are underestimated and density is therefore overestimated by an unknown amount. A common event in this kind of vegetation is for the centre of a tuft to die under adverse treat-

Table 3. *Importance values obtained by each operator for each of the eight methods for the twelve most prevalent species on Site* 1

Method:	1			2			3			4			5			6			7			8		
Unit of measurement:	% basal cover			% basal cover			% basal cover			Density/m²			Relative density			Relative density			Frequency			% by weight		
Operator:	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Loudetia simplex	1·95	1·82	2·57	2·67	2·67	2·24	2·57	2·40	2·33	23·0	17·5	27·3	0·243	0·248	0·265	0·218	0·247	0·248	63	59	70	35·0	30·8	31·7
Diheteropogon amplectens	0·53	0·63	1·08	0·80	0·80	0·75	0·77	1·03	1·27	22·1	19·0	19·5	0·207	0·181	0·199	0·220	0·200	0·190	79	74	77	15·5	20·4	22·4
Heteropogon contortus	0·54	0·52	0·76	0·64	0·48	0·37	0·27	0·50	0·43	13·8	13·0	19·0	0·119	0·136	0·135	0·137	0·108	0·118	67	63	64	12·1	13·2	8·0
Hyperthelia dissoluta	0·15	0·23	0·27	0·27	0·27	0·27	0·20	0·17	0·27	5·9	3·4	6·3	0·047	0·035	0·050	0·057	0·027	0·052	40	29	31	9·1	5·2	14·4
Hyparrhenia filipendula	0·14	0·27	0·49	0·48	0·16	0·21	0·23	0·30	0·43	6·0	4·6	3·6	0·024	0·062	0·041	0·043	0·060	0·060	36	38	29	12·3	13·0	13·4
Rhynchelytrum repens	0·22	0·19	0·22	0·27	0·05	0·27	0·23	0·40	0·33	6·5	5·0	8·5	0·062	0·064	0·058	0·055	0·072	0·063	31	47	31	1·5	4·0	0·7
Helichrysum nudifolium	0·03	0·02	0·04	0·05	0·05	0·16	0·03	0·03	0·13	4·6	4·5	3·5	0·019	0·015	0·019	0·028	0·033	0·023	27	22	21	1·0	0·8	0·9
Cassia biensis	0·01	0·01	–	–	–	–	–	–	–	2·1	3·4	2·0	0·022	0·027	0·013	0·005	0·018	0·015	27	26	21	–	–	–
Bulbostylis collina	0·05	–	0·02	0·05	0·05	0·16	0·03	–	0·03	4·0	1·0	0·4	0·022	0·027	0·023	0·022	0·017	0·028	27	29	17	–	–	–
Chloridion cameronii	0·06	0·07	0·10	0·11	0·05	–	0·07	0·13	–	3·8	4·8	2·9	0·020	0·036	0·014	0·025	0·022	0·023	21	22	16	–	–	–
Pogonarthria squarrosa	0·02	0·01	0·02	0·05	0·05	0·05	–	0·10	0·07	3·3	2·4	1·7	0·032	0·025	0·017	0·032	0·017	0·012	14	23	17	–	–	–
Cyperus spp.	0·01	0·01	0·09	0·05	–	0·11	–	–	–	1·8	0·1	3·3	–	0·012	0·010	0·010	0·005	0·005	13	10	16	–	–	–
Total no. of species	31	27	26	19	14	16	18	18	16	34	31	30	32	27	30	31	23	26	46	37	39	20	21	23

Table 4. *Importance values obtained by each operator for each of the eight methods for the twelve most prevalent species on Site 2*

Method:	1			2			3			4			5			6			7			8		
Unit of measurement:	% basal cover			% basal cover			% basal cover			Density/m²			Relative density			Relative density			Frequency			% by weight		
Operator:	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Themeda triandra	3·54	3·73	3·35	3·89	3·57	4·32	3·0	4·9	3·83	43·9	51·2	44·9	0·366	0·386	0·375	0·331	0·433	0·350	82·6	83·3	79·5	46·3	49·2	42·7
Heteropogon contortus	1·34	1·14	1·67	1·28	1·17	1·67	0·77	1·47	1·97	16·4	20·6	20·3	0·154	0·215	0·172	0·150	0·163	0·165	56·7	49·3	54·6	22·8	26·4	19·9
Cymbopogon plurinodis	0·92	0·84	1·36	1·12	0·75	1·36	2·0	1·0	2·07	5·8	6·0	9·0	0·072	0·057	0·084	0·095	0·065	0·100	37·3	32·6	38·6	21·8	9·7	17·1
Digitaria pentzii	0·09	0·10	0·06	0·27	–	0·32	0·07	0·03	0·07	45·7	48·9	36·7	0·230	0·165	0·186	0·262	0·220	0·205	66·0	62·0	64·0	3·4	5·6	5·7
Bothriochloa insculpta	0·38	0·23	0·30	0·37	–	0·59	0·23	0·03	0·13	5·0	0·6	4·9	0·046	0·029	0·040	0·025	0·020	0·037	15·3	10·6	15·3	2·2	0·2	3·7
Rhynchelytrum repens	0·04	0·08	0·06	0·11	0·11	0·11	0·07	0·03	0·13	1·9	1·5	3·1	0·017	0·030	0·035	0·035	0·018	0·027	10·6	8·6	13·3	–	–	–
Setaria porphyrantha	0·22	0·28	0·36	0·43	0·28	0·11	0·23	0·13	0·26	2·4	2·4	4·9	0·007	0·017	0·017	0·020	0·013	0·018	8·6	8·7	9·3	1·5	0·7	3·5
Solanum panduriforme	–	–	–	–	–	–	–	–	–	1·5	1·0	1·4	0·008·	0·010	0·003	0·012	0·003	0·002	7·3	8·0	10·6	–	–	–
Hyparrhenia filipendula	0·29	0·17	0·17	0·16	0·05	0·11	0·03	0·27	0·13	1·0	0·3	1·1	0·010	0·006	0·012	0·003	–	0·010	3·4	2·0	4·6	–	–	–
Cymbopogon excavatus	0·04	0·06	0·06	0·05	–	0·11	–	–	–	0·4	1·8	0·8	0·005	0·010	0·002	0·005	0·005	0·012	2·0	5·6	1·2	–	–	–
Eragrostis superba	–	–	–	–	–	0·05	–	–	–	0·3	–	–	–	–	–	–	–	–	2·0	2·0	0·6	–	–	–
E. atherstonei	0·01	–	–	0·16	–	–	–	–	–	0·6	–	0·6	–	–	–	–	–	–	3·4	1·2	2·0	–	–	–
Total no. of species	15	13	17	12	6	11	11	10	12	18	16	18	19	16	21	17	14	18	18	21	22	10	14	13

ment. With measurement to the edge of a tuft, the full extent of this decrease in rooted plant material will not be recorded because, where basal cover is of the order of 5 or 6%, the point will only strike a tuft five or six times in every hundred. The remainder will all record much the same mean distance as existed before the centres of the tufts died. Consequently, only measurement to the centre of an individual should be made as this will at least give an estimate of density unconfounded by cover.

With respect to the relative densities of individual species obtained by the PCQ, the number of points required for all but the two or three most abundant species preclude the use of the PCQ approach (Heyting 1968). The estimates obtained in this study (Tables 3 and 4) show considerable variation between operators for the less abundant species. Using quadrat counting, sample sizes required for estimating the densities of individual species increase to much the same extent as they do with the cover estimates.

Frequency

The estimates of frequency from both sites exhibit some differences between operators (Tables 3 and 4), but in general there is fairly good agreement. It is the only method that provides adequate estimates of importance values for all species without the necessity to increase the sample size to an impracticable level. More species were encountered with frequency sampling than with any other method (Tables 3 and 4).

Table 5. *Averaged values from the three operators for required times (in hours and minutes) and sample sizes for a 20% confidence interval* (P = 0·05), *for the estimates of total basal cover and total density*

	Method no.					
	1	2	3	4	5	6
Site 1						
No. of samples	30	1875	30	90	250	150
Required no.	11	1750	16	48	30	17
Time taken	8:49	3:42	1:40	3:07	4:50	4:07
Required time	3:11	3:19	0:51	1:41	0:35	0:28
Site 2						
No. of samples	30	1875	30	90	240	150
Required no.	8	1625	9	24	27	14
Time taken	5:53	3:56	2:22	3:13	3:25	4:11
Required time	1:30	3:36	0:42	0:56	0:24	0:23

Dry-weight-rank technique

Differences between operators were in general too great for the results to be acceptable (Tables 3 and 4). Relatively few species were encountered during the ranking procedure and, consequently, the contributions of the remainder to the weight of the sward could not be estimated. Although the individual contributions of the latter may be negligible, their combined weights are undoubtedly significant. Therefore, in order to obtain accurate estimates for the species that do attain rank, the remaining species must be treated collectively as a single unit, and must be included as such in the ranking procedure.

For all methods the required number of samples was, on the average, much greater for Site 1 than for Site 2 (Table 5). This was largely due to the fact that Site 1 is more heterogeneous. In general, the vegetation on Site 1, and the area surrounding it, is dominated by *Hyperthelia dissoluta*, *Hyparrhenia filipendula* and *Heteropogon contortus*. Throughout this basic community type, however, areas dominated by *Loudetia simplex*, in addition to the species just mentioned, occur in an irregular pattern. Two such areas, both about half an acre in extent, occurred at each end of the site. The differences in density and cover between these community types resulted in the large increase in required sample size, relative to Site 2 which consisted of a single community type.

One rather surprising aspect of the results is that, within methods, the three operators achieved different variances. It was originally thought that although the operators may obtain different means the variances would be very similar as the latter would be determined by the pattern of vegetation.

DISCUSSION AND CONCLUSIONS

A number of practical points emerged during the course of this trial, and the more important of these will be discussed together with some of the theoretical implications arising from the results obtained.

All methods were more difficult to use, though to different degrees, in grassland in which a mass of dead matter had accumulated. In the cover estimates, the line intercept is affected least since it involves a continuous and relatively slow movement over a restricted area of ground. The wheel-point is affected most, as the number of times that the instrument must be stopped and the area of contact examined is considerably increased. The extra stress on the operator is a most important factor as fatigue is likely to lead to errors. When one spoke of the wheel is used, the observer has to walk almost 4 miles to obtain 2000 points. In Site 2 about one in every four points had to be checked, therefore necessitating about 500 close examinations.

Where the individual plants are discrete and easily recognized, measurement using the variable plot method is relatively easy, but where the tufts are indistinct or broken up the method becomes subjective and more laborious.

A factor of considerable importance in all cover estimates is the size of gap in a tuft which is considered to be either dead material or bare ground, as the case may be, as opposed to continuous, live material. Gaps range from 1 or 2 mm to several centimetres and a strict definition is very difficult to apply. With experience the problem diminishes, but this aspect is considered to be a potential source of error in all cover estimates.

The PCQ method and quadrat counting become rather subjective where, as generally occurs in natural grasslands in this region, tufts begin to break up into separate individuals as a result of age, fire, grazing, etc. The definition of an individual becomes all important and the decisions as to the degree of fragmentation that constitutes separate individuals completely determines the results obtained. The problem of seedlings and individual tillers arising at some distance from a parent tuft also adds to the confusion. The effect is worse in the PCQ where the relative densities obtained for each species depend on the values for all other species.

Frequency is the most straight-forward method as the only stipulation is that some rooted, living material of a species be inside the quadrat for that species to be recorded. It does, however, require a preliminary survey to determine the most suitable size of quadrat. It is well suited to the comparison of values for an individual species obtained at different times on the same site. It is essential that quadrat size remain the same for any one species, but two, or even more, sizes may be used to sample the full range of species on any one site (Hyder *et al.* 1965). Where a comparison of species composition in two or more very different vegetation types is required, such that optimum quadrat sizes for the types differ, frequency may be of limited use.

The DWR approach has few practical problems, barring the fact that it requires considerable experience and practise in heterogeneous communities in order to rank correctly. In addition to the drawbacks mentioned in the presentation of results, the estimates obtained are influenced by species dispersion. A species with a low total weight which is regularly distributed throughout the area, will achieve a lower rating than one of equivalent weight that is highly aggregated.

Considering both the results obtained and the practical implications of the methods, the conclusions drawn from the trial can be summarized as follows. The line intercept, which was originally included chiefly as a standard against which the two other cover estimates might be tested, is in the final analysis recommended as the best method, under these conditions, for obtaining a reliable estimate of total basal cover. Experience since the trial was completed has shown that the use of a wire 5 m long instead of 10 m is preferable. The shorter wire is more easily handled and enables the wire to be placed closer to the soil surface. In addition it results in an increased sample size for the time spent, and therefore more precision. Whitman & Siggeirsson (1954), comparing the line intercept and frame of ten points, indicate the line intercept to be the more favourable, for basal cover, with respect to variability and upward bias in the estimate obtained. The wheel-point was the next best of the cover estimates and it is possible that in denser types it may prove to be more feasible.

The distance methods give rapid, though somewhat biased, estimates of total density provided measurement is made to the centre of a tuft. However, a density figure alone provides limited, and possibly misleading, information and is of questionable value in this kind of vegetation.

Frequency is the only method that gives an adequate estimate of the importance of all species. Changes in the abundance of both dominant and minor species are recorded with sufficient accuracy to be acceptable, whereas for the same confidence intervals the other methods tested require very large increases in expenditure of time. Whitman & Siggeirsson (1954) reached a similar conclusion (with respect to time required for cover estimates) working on a 60% probability level for 5% accuracy. Frequency is not, however, an absolute measure such as basal cover or density, and the values obtained reflect both the density and dispersion of the species concerned.

The DWR method requires considerable practise and for this vegetation, with its large number of species, appears to be of limited use.

No single method can provide all the answers being sought and it is an essential prerequisite of any trial that the information wanted be clearly defined in terms of the various vegetation parameters. Once defined, the choice of the particular method best suited to that (or those) parameter(s) should be made along lines similar to those described in this paper. As a result of this trial it is suggested that, for an ecological interpretation of range use trials, an estimate of total basal cover by the line intercept, plus an estimate of the frequency of each species, will give the most useful information for the time spent. Owing to the large increase in required sample size that occurs when more than one community type has to be included in a single estimate, it is well worth the extra effort involved in planning and locating the units of a trial so as to prevent, if possible, such situations arising. Differences between estimates obtained by the three operators were a major feature of the results and, wherever possible, the same operator should be responsible for botanical analysis of the same site at different times.

One of the most significant, though perhaps rather obvious, points that emerged from this study was the importance of the human factor. Every method is entirely dependent on the integrity and attitude of the operator. Human stress is a significant factor in most botanical analysis techniques and may easily invalidate the results obtained. A decline in concentration in all three operators resulted from physical stress in the case of the wheel-point and, to a lesser extent, in the line intercept. Likewise, a noticeable drop in enthusiasm occurred during PCQ measurements. In order to obtain reliable, repeatable results it was found necessary in this study to limit actual sampling time to between 4 and 5 h a day.

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SUMMARY

Two grassland sites on the Matopos Research Station in Rhodesia were analysed by three different operators using the line intercept, wheel-point, variable plot, quadrat count, point-centred-quarter, angle order, quadrat frequency and dry-weight-rank techniques. Density appears to have limited ecological value for range research in this type of vegetation. Both distance methods gave rapid, though rather biased, estimates of density. The line intercept is recommended as the best of the cover estimates for this vegetation on the basis of precision and efficiency. Frequency was the only method to provide acceptable estimates of the importance of all species without the expenditure of excessive amounts of time. The dry-weight-rank method had a number of deficiencies and resulted in excessive variation between operators.

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