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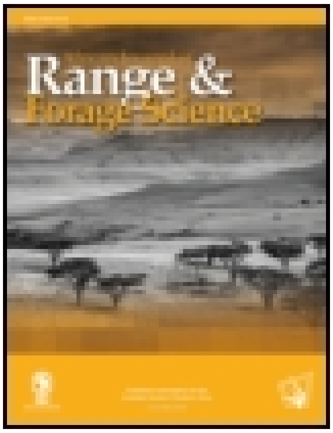

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Visual obstruction as a method to quantify herbaceous biomass in southern African semi-arid savannas

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Biomass of aboveground vegetation is a useful descriptor for studies of grazing, fire and wildlife habitat use in grassland systems. The traditional method to estimate biomass, hand-clipping, is time intensive and other indices of biomass have been used successfully. In southern Africa, the disc pasture meter has been the tool of choice and the use of visual obstruction has been much less prevalent than in North America. Our goal was to determine if visual obstruction could be used as a correlate to aboveground grass biomass in grassland systems in Namibia. We gathered clipping and visual obstruction samples at three study sites in Highland Savanna and Woodland Savanna in northern Namibia. Dry biomass of grass was correlated with visual obstruction readings when samples from all study sites were pooled ($r^2 = 0.64$, $P < 0.0001$), but the strength of the relationship varied among the three study sites. We also evaluated the number of samples needed to characterise biomass at a study site. Variation in the cumulative mean was very low at sample sizes of 15–20 samples. Visual obstruction can be a useful method to evaluate biomass of grassland systems in a quick manner.

Keywords: biomass, grassland, range pole, visual obstruction, wildlife habitat

Introduction

Estimates of aboveground biomass are often needed for studies of grazing, fire and wildlife habitat. Farmers also need to estimate biomass to determine carrying capacity of their rangelands for domestic or wild grazing animals. The traditional method for estimation of biomass has been hand-clipping. The method requires samples to be clipped, dried and weighed from plots of a known area. The technique provides an accurate assessment of biomass, but clipping is labour intensive and slow (Volesky et al. 1999) and is destructive.

Tucker (1980) reviewed several methods for non-destructive estimates of biomass that require less sampling time. Robel et al. (1970) reported that visual obstruction (VO) and biomass were highly correlated ($r^2 = 0.95$) in a tallgrass prairie in Kansas, USA (mean biomass 232 g m^{-2}). Obstruction was quantified using a round pole ('range pole': Lutz et al. 1994; 'Robel pole': Best et al. 1998) with alternating 1 dm bands painted dark and light. The lowest decimetre mark visible on the pole was recorded as the obstruction measurement.

Visual obstruction is commonly used as a measure of cover density (Higgins et al. 2005) and is a functional parameter in wildlife-related studies. Higher degrees of obstruction of the Robel pole correlate with more aboveground biomass, and greater obstruction indicates more cover for birds and small mammals for nesting, escaping predators and thermo-regulating body temperatures (Higgins et al. 2005). For these reasons, visual obstruction has become a standard measure used by wildlife managers and researchers in North America to assess habitat suitability and habitat preference (Reece et al. 2001, Higgins et al. 2005). We conducted a literature search and were unable to find a single published use of VO in southern Africa. However, the disc pasture meter (Bransby and Tainton 1977) has been used extensively in southern Africa, which suggests a similar need by ecologists to quickly sample for a variety of purposes.

Robel et al. (1970) suggested that VO readings also could be a time-saving method to estimate grassland biomass. Subsequent research has indicated that the relationship of the VO measurement with biomass is site-specific. Volesky et al. (1999) and Benkobi et al. (2000) modified the pole by dividing the 1 dm bands into 2.5 cm zones in an attempt to improve the accuracy of biomass predictions from VO measurements in shorter grass systems. However, Volesky et al. (1999) reported variability in the relationship between VO and aboveground biomass in a mixed grass prairie in the central USA (mean biomass 148.4 g m^{-2}).

Our goal was to assess the VO technique on semi-arid grasslands in southern Africa. Our objectives were (1) to determine if VO could be used as a correlate to aboveground grass biomass, (2) to evaluate the number of samples needed to characterise a given study site's biomass, and (3) to use our results to provide suggestions to guide implementation of VO in a sample scheme.

Materials and methods

Field methods

We collected samples of vegetation at three study sites. Two sites (Neudamm5 and Neudamm7) were located at the Neudamm Agricultural College in the Highland

Savanna region (Giess 1971) east of Windhoek, Namibia. The Highland Savanna is considered a semi-arid savanna (Coetzee 1998) and precipitation is highly variable and seasonal: 80% of the annual rainfall occurs from January through March. Windhoek's long-term mean annual rainfall (1892–2003) is 361 mm. The terrain is broken and undulating, at altitudes of 1 350–2 400 m above sea level. The third study site (Waterberg) was located on the Waterberg Plateau in the Woodland Savanna region (Giess 1971), south-east of Otjiwarongo, Namibia. The plateau is approximately 1 600 m above sea level; the mean annual rainfall is approximately 500 mm (du Preez 2001).

The three study sites were chosen as contrasting grassland sites. Joubert (1997) and Erb (1993) provided characterisations of the woody and non-woody vegetation at our study sties. The two Neudamm sites represent subclimax (Neudamm5) and climax savanna (Neudamm7) based on subclimax grass species (*Schmitdia pappo-horoides* at Neudamm5) and climax grass species (*Anthephora pubescens* and *Brachiaria nigropedata* at Neudamm7) being the dominant grasses in terms of biomass and cover. Neudamm5 had a more varied vegetation cover than Neudamm7. A significant portion of the grass biomass and cover at Neudamm5 was the annual grass, *Melinis repens* subsp. *grandiflora*; there was scant contribution to cover and biomass by the climax grasses *A. pubescens* and *B. nigropedata*. The Waterberg study site contrasted with the Neudamm sites because of the dominance of woody species and unpalatable, coarse grass species such as *Eragrostis pallens*. Grasses at Waterberg were generally at lower density but with higher tufts than grasses at Neudamm.

We estimated VO and sampled biomass during October 2009 (at Neudamm5), during November 2009 (at Neudamm7), and during October and November 2010 (at Waterberg). Our sampling was serendipitous because of the need to determine aboveground biomass for fuel-load estimates prior to a prescribed burn. At each study site, we established three parallel, 100 m lines with a random start point, and we sampled at 10 m intervals, resulting in 30 samples at each site. Our sample spacing and number was selected to characterise the size of the c. 1 ha sites. At each 10 m interval, we selected a random direction (left/right) and distance (0–5 m) from the line as the centre of a 1 m^2 quadrat. We took VO readings of a Robel pole placed at the centre of the quadrat, and we then hand-clipped all standing vegetation in the quadrat at a height of 2 cm. The clipped samples were bagged, dried at 60 °C for 5 d (after which samples had stabilised in mass) and weighed with an electronic balance.

The Robel pole was a 2 m PVC (32 mm diameter) pole painted in alternating 1 dm bands of red and white. Each band was subdivided into four 2.5 cm regions (Figure 1). At each sample location, four readings were taken at 4 m from the pole in the cardinal directions. When woody vegetation prevented a view of the pole, the observer moved 1 m to the side. Each reading was taken at an eye-height of 1 m (Figure 1). We used a 1 m wooden stick or a second Robel pole (Figure 1) to keep our eye-height constant. We recorded the lowest region of the pole that was 100% obscured by vegetation (modified from Robel et al. 1970). The mean of the four readings at each sample point was used as the VO measurement for that point.

Statistical methods

We characterised the sample from each study site with descriptive statistics: mean, standard deviation and 95% confidence interval (CI). To assess the ability of VO to effectively predict dry biomass of grass within a 1 m^2 plot, we first evaluated the correlation with the PROC CORR procedure in SAS version 9.2 (SAS Institute, Cary, NC,

Figure 1: Method for taking a visual obstruction reading with a Robel pole (A) at a distance of 4 m, at a height of observation of 1 m (here, observation height is measured with a secondary Robel pole; B). Inset shows visual obstruction of vegetation against a Robel pole with 1 dm colour divisions with 0.25 dm markings

USA) between dry biomass of grass (g m^{-2}) and VO. We transformed the Pearson r to r-squared to assess proportion of variability explained by the relationship. We then inspected plots of our data and decided that linear models were most appropriate to describe relationships for which we had interest. Thus, we used a linear regression model to assess variability of dry biomass using the PROC GLM procedure in SAS with main effects of VO reading and study site. We also considered the interaction between VO and study site to determine if the linear relationships of dry biomass and VO varied among our study sites.

To evaluate the number of samples needed to characterise a given study site's biomass, we selected one of our study sites (Waterberg), because Waterberg met our needs for (1) sample values across the gradient of possible VO in the region (0–4 dm) and (2) samples with higher variability (lower r^2). The number of samples needed can be affected by the variability of vegetation density within the landscape (McCabe 2012). We valued a sample with higher variability as it did not represent best-case scenarios. Thus, our approach should lead to conservative suggestions for sample sizes. We emphasise that our sample size exploration was specifically designed to assess the number of samples needed to adequately characterise a study site's biomass, which was required in our exercise to prepare for a prescribed fire.

Plant and animal ecologists commonly use species-area curves to determine the size of a sample area where the number of species to be observed in an area has been reached and further sampling is wasted effort (e.g. Kenkel and Podani 1991). Following this logic, if the central tendency of a study site's biomass is desired, cumulative means can be used in the same manner as species area curves: after a given sample size, the variability within a site has been accommodated and the cumulative mean does not change. Thus, further samples are not needed to characterise the study site. To perform this exercise, we arranged the 30 samples from Waterberg according to the order of our original collection. However, it is possible that our systematic sampling followed a gradient of biomass within the study site. To avoid this possibility for bias, we randomly ordered our sample, and we performed 10 simulations of the random ordering. We used a random number generator in a spreadsheet to produce a random number in the interval 0–1 for each sample. We then ranked the samples by the magnitude of their associated random number, which rearranged the order of our samples to simulate a randomly ordered sample taken at the Waterberg site. We then computed the cumulative mean of sample sizes of 1–30, and we repeated this simulation 10 times. The 10 replications then represented 10 possible orders of our samples taken at Waterberg. We computed the mean of the cumulative means for each sample size, 1–30, across the 10 replications. We calculated the 95% CIs of the means of the cumulative means as:

$$\frac{1.96 \cdot \sigma}{\sqrt{n}}$$

where σ is the standard deviation of the mean and n represented our sample size. We compared the cumulative means of smaller sample sizes to the known mean from our 30 samples at the Waterberg study site. To assess the magnitude of the advantage of adding an additional sample, we calculated the absolute value of the difference between the cumulative mean at sample sizes of i and $i - 1$ for sample sizes of 2–30. Again, we calculated the mean of the absolute differences across the 10 replicates, and we calculated 95% confidence intervals for these means.

Last, to estimate the sample size (n) needed to estimate mean VO at differing levels of accuracy (ϕ = 0.10, 15 and 20; as a proportion of the study site mean), we used our estimates of the coefficient of variance (CV) and a t-statistic (α = 0.05, df = 29) from the 30 samples at each study site, as suggested by Eckblad (1991):

$$n = \left[\frac{\text{CV} * t_{0.05}}{\varphi} \right]$$

Results

The Neudamm5 site had lower dry biomass of grass and VOs than the other two study sites (Table 1). Dry biomass of grass was correlated with VOs when samples from all study sites were pooled (r^2 = 0.64, P < 0.0001), but the strength of the relationship varied among the three study sites (Neudamm5: r^2 = 0.38, P < 0.001; Neudamm7: r^2 = 0.72, P < 0.0001; Waterberg: r^2 = 0.54, P < 0.0001; Figure 2). The linear model confirmed that dry biomass (g m^{-2}) was predicted by VO ($F_{1,88}$ = 49.66, P < 0.001). The model also suggested that the relationship between the dry biomass of grass and VO differed in a non-parallel manner among the three study sites (additive effect of location: $F_{2,88}$ = 1.47, P = 0.23; VO*location interaction: $F_{2,88}$ = 3.49, P = 0.035; Figure 3).

The mean of our 10 replicates of cumulative means of VOs quickly approached the actual mean by a sample size of n = 3. However, there was considerable variation about the mean (Figure 4a); the variation was reduced after n = 15 and variability was very low when sample sizes were >20. Similarly, the mean absolute difference in cumulative means of VOs of a given sample size and one additional sample became stable when sample sizes were >15 (Figure 4b). The number of samples suggested for estimating means at an accuracy of ϕ = 0.20 varied between 42 and 101 (Table 2).

Discussion

Visual obstruction/biomass relationships

We show that VO readings can be used to predict biomass of vegetation with moderate to high levels of certainty in grasslands in Highland Savanna in Namibia. However, the relationships varied among our study sites (Figures 2 and 3). One dominant factor leading to variation in the

Table 1: Mean (±SD) and 95% confidence intervals (CI) from samples of dry biomass (g m^{-2}) of clipped grass and visual obstruction readings (VO; dm) at three study sites in Namibia during 2009 and 2010

Study site	Biomass (g m⁻²)		VO (dm)	
	Mean ± SD	95% CI	Mean ± SD	95% CI
Neudamm5	100.6 ± 43.0	84.5–116.7	0.48 ± 0.31	0.37–0.60
Neudamm7	181.0 ± 131.2	132.0–230.0	1.30 ± 0.86	0.98–1.62
Waterberg	136.9 ±111.1	94.6–179.2	1.02 ± 1.00	0.64–1.40

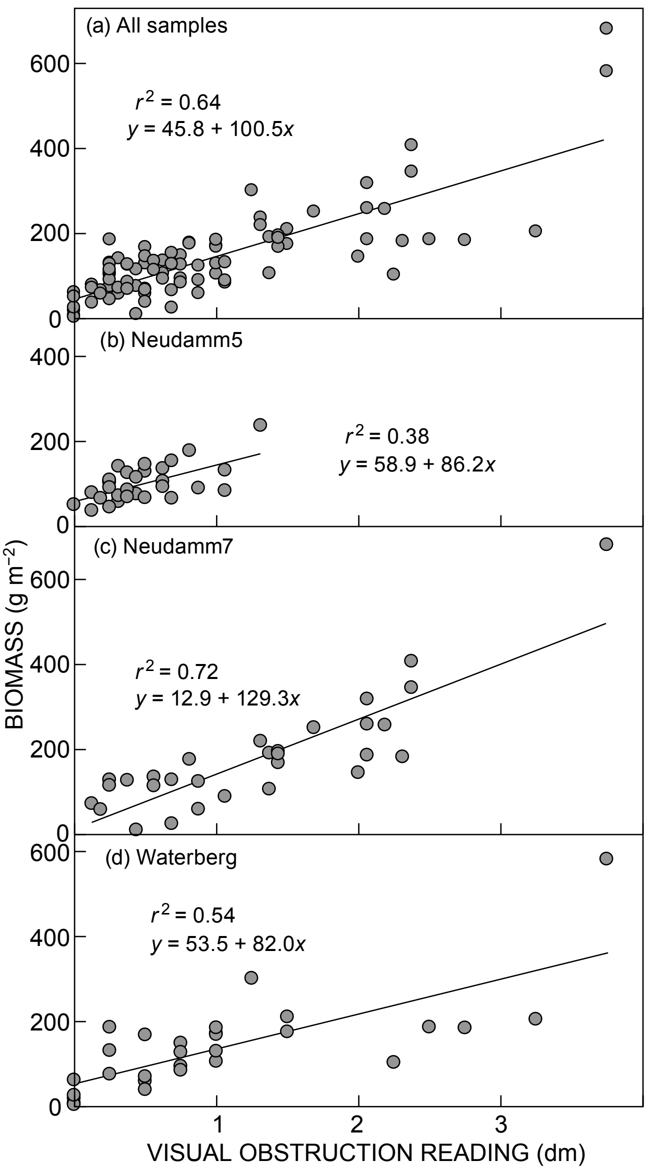

Figure 2: Linear relationship of dry biomass of grass clippings and visual obstruction reading measured at three study sites (a) in Namibia during 2009 and 2010. Individual study site relationships are shown for (b) Neudamm5, (c), Neudamm7 and (d) Waterberg

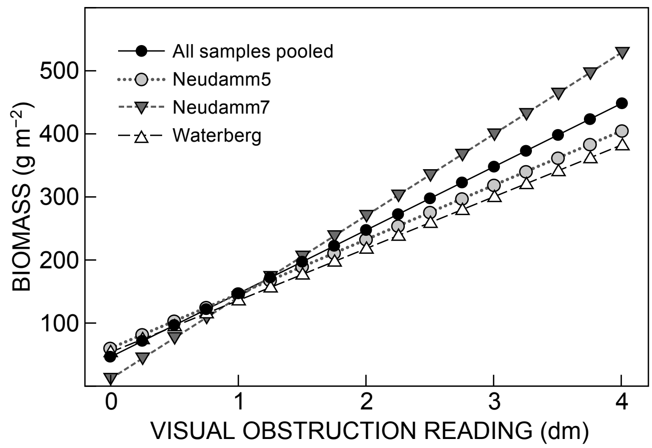

Figure 3: Predicted values (based on equations shown in Figure 2) of dry biomass (g m^{-2}) across a gradient of visual obstruction readings based on model results from data collected from three study sites in Namibia during 2009 and 2010

relationship between biomass and VO was the structure of the vegetation at the study sites. At the Waterberg site, the grass was tall but less dense than Neudamm's two study sites, at which we observed that the grass tufts were short and densely packed. Visual obstruction requires complete obstruction on the measuring pole. Thus, tall and sparse vegetation may have the same biomass as shorter, thicker vegetation, but the tall, sparse vegetation may be measured as lower in VO because the vegetation does not completely obscure the pole. For this reason, we recommend that research biologists develop local, site-specific relationships for biomass and VO for predictive use.

Similarly, we found varying moderate to high (Hemphill 2003) levels of correlation of biomass and VO among our study sites (Waterberg: $r^2 = 0.54$, Neudamm5: $r^2 = 0.38$, Neudamm7: $r^2 = 0.72$). When we pooled all of our samples, biomass and VO were highly correlated ($r^2 = 0.64$). Previous studies in North America have resulted in higher levels of correlation in tallgrass prairies in subhumid regions (Robel et al. 1970; Limb et al. 2007; mean annual precipitation of 760–915 mm) than in mixed-grass prairies in semi-arid regions (Volesky et al. 1999; Anderson 2012; mean annual precipitation of 500–610 mm). However, the lower levels of correlation in semi-arid grasslands are not explicitly an indicator of higher sampling error for the relationship between biomass and VO. By their nature, semi-arid grasslands (within a given year) have a lower range of VOs and biomass across the landscape than subhumid grasslands. In a subhumid, tallgrass region Limb et al. (2007) reported a range of VO of 0–6 dm and a range of biomass of c. 0–900 g m^{-2} ($r^2 = 0.68$); in contrast, Volesky et al. (1999) in a semi-arid, mixed-grass region reported ranges of visual obstruction readings (VOR) of 0–3 dm and 0–2.2 dm and ranges of biomass of c. 0–400 g m^{-2} ($r^2 = 0.41$) and c. 0–500 g m^{-2}.($r^2 = 0.31$). Statistically, given equal sample sizes and standard deviations around a linear relationship, a set of values with a smaller range of the independent variable (semi-arid VO) will have a smaller amount of its variance explained by the linear relationship than a set of values with a larger range of the independent variable (subhumid VO; Lefsky et al. 1999). Thus, semi-arid grasslands should be expected to exhibit lower levels of correlation between VO and biomass than subhumid grasslands.

We suggest that biologists avoid the conclusion that VOR should not be considered for use in semi-arid grasslands, based solely on relatively low values of r^2 when comparing VO and biomass. However, our data suggest that semi-arid grasslands do present a unique challenge to the interpretation and use of correlates of biomass, such as VO. Sampling variability in structure found within a smaller range of structural values should create more apparent uncertainty (as measured by low r^2) in the predictions from correlative tools. When predictions of biomass are the objective, we encourage biologists to construct CIs of their model's prediction to assess predictive certainty. The CIs for the biomass

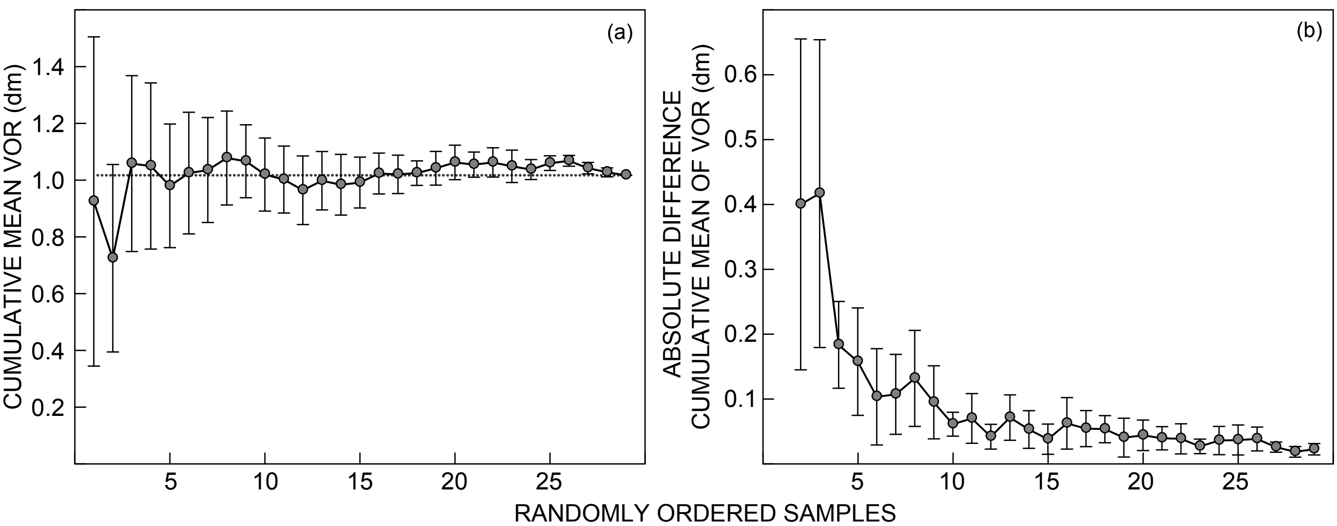

Figure 4: Mean and 95% confidence intervals (CIs) of cumulative means of visual obstruction readings (VOR) from 10 randomly ordered simulated samplings of data from the Waterberg study site (a) in Namibia during 2009 and 2010; the dotted line is the known mean of the sample ($n = 30$). Absolute differences and 95% CIs of the cumulative VO means for sample i and $i - 1$ from the 10 simulations (b)

Table 2: Sample sizes needed to estimate mean visual obstruction at varying levels of accuracy, based on samples obtained from three study sites in Namibia during 2009 and 2010

Study site	Levels of accuracy (proportion of mean)		
	0.10	0.15	0.20
Neudamm5	169	75	42
Neudamm7	183	82	46
Waterberg	404	179	101

estimate can be evaluated relative to the reason for making the prediction. Higher precision may be needed when predicting biomass as the forage base for a specific number of grazing animals, whereas lower precision may be acceptable if a biologist must assess biomass of a study site in meeting the biomass threshold needed to carry a prescribed fire. In addition, when the objective is to compare relative biomass among study sites, VO should be very useful (regardless of low values of r^2). However, more samples will be required to provide the statistical power to detect differences between two study sites in semi-arid grasslands than would be required in subhumid grasslands, because the difference between the means of the two semi-arid sites will typically be less than two subhumid sites.

Visual obstruction as a field technique

In the field, assessment of biomass by VO takes less time than clipping, drying and weighing vegetation samples. Thus, VO may be useful in rapid assessments of vegetation and VOR can be a good covariate to gather for analyses of habitat use by wildlife (Higgins et al. 2005). In Nebraska, USA, we have found VO to be a valuable descriptor of nest sites and brood-rearing sites of ring-necked pheasants (Matthews et al. 2012; *Phasianus colchicus*) and greater prairie-chickens (Anderson 2012; *Tympanuchus cupido*), even in a system in which VO was poorly to moderately correlated to biomass (Anderson 2012; $r^2 = 0.06–0.28$). We recommend wildlife biologists in southern Africa consider VO as a measure to describe grassland habitat during field studies, as it is widely used with success in describing animal habitat use and selection in North America (Reece et al. 2001; Higgins et al. 2005). Our literature search found no uses of VO in research published in southern Africa.

The pole used for VO measures is an inexpensive tool to construct and a light tool to carry long distances through study sites in grassland areas. A similar tool, which has been used widely in southern Africa, is the disc pasture meter (Bransby and Tainton 1977). The meter consists of a measurement pole along which a disc slides down to rest on the bulk of vegetation below the disc. Sharrow (1984) provided plans for an inexpensive, light version of the pasture meter, which can be bulkier than the poles used for VO when the disc pasture meter is made of metal. The disc pasture meter can be used by one person; visual obstruction readings can be also obtained by a single technician if a spike is placed on the main pole (Figure 1a) to allow it to stand freely in loose soils.

Measures of forage bulk from the disc pasture meter have typically been highly correlated with biomass of vegetation (Bransby and Tainton 1977; Sharrow 1984). However, Zambatis et al. (2006) found that readings from the disc pasture meter could be influenced by the structure of the dominant plants found at a given study site, just as we found for visual obstruction readings among our study sites in Namibia. The prevalent uses of the disc pasture meter in southern Africa and VO in North America appear to be a result of professional familiarity and word-of-mouth transfer of information rather than beneficial traits of either method.

Sampling recommendations

Our randomisation simulations suggest that our study sites should be sampled with at least 15 measures to confidently characterise biomass. In addition, our simulations suggested little value in collection of >15–20 samples, based on cumulative mean and the 95% CI about the mean.

However, the CVs of our measures of VO were high and our secondary sample size analysis suggested that 40–100 samples could be required to determine the true mean of a population within an accuracy level of 0.20 (0.20 of our means ranges 0.10–0.26 dm), with similar CVs to our initial samples. Similarly, Dörgeloh (2002) used an assessment of CV levels to suggest at least 100 measures with the disc pasture meter in Mixed Bushveld in northern South Africa. Trollope and Potgieter (1986) also suggested no benefits of more than 100 samples with the disc pasture meter.

Of course, sampling recommendations depend on the objective of the assessment in question. When the objective is to characterise a given unit of the landscape for forage availability or potential to carry a fire, multiple measures should be taken to account for the variability of vegetation throughout the landscape. Our simulations suggest that 15–20 measures are needed for VOs at the Waterberg study site. When one landscape is to be compared to another landscape, or when comparisons will be made between samples taken before and after a treatment, statistical power depends on sample size. More samples may be necessary in such cases (Dörgeloh 2002). In contrast, when visual obstruction readings are used to characterise vegetation at a single point, such as a bird's nest or a specific location of an animal for habitat use analyses, a single measurement is used to compare to random locations in the study area (Matthews et al. 2012).

Conclusion

Visual obstruction readings are a suitable alternative to the disc pasture meter as a proxy measure for biomass in grasslands. We encourage biologists to develop site-specific predictive models to account for variation in structure of vegetation, regardless of method used to collect data.

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