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ABSTRACT We used a modified Robel pole to measure vegetation for a study conducted in the northern Black Hills, South Dakota. Objectives were to determine the relationship between visual obstruction readings and clipped standing herbage, and develop guidelines for monitoring standing herbage. The relationship between visual obstruction readings and standing herbage was linear and regression coefficients were significant ($P \leq 0.001$). Herbage ranged from 140 to 3313 kg·ha^{-1} with a mean of 1386 kg·ha^{-1} (SE = 320 kg·ha^{-1}) for 123 transects. Visual obstruction readings (VOR) ranged from 0.6 to 30.4 (number of 1.27 cm bands obscured) with a mean of 10.9. Cluster analyses grouped the visual obstruction readings and standing herbage into 3 VOR categories; short, intermediate, and tall. Our results indicate a minimum of 4 transects (20 stations/transect) is needed to be within 20% of the mean at 80% confidence for monitoring areas ≤ 259 ha (1 section). The protocol we developed provides pertinent information for managers to develop guidelines and monitor standing herbage for livestock and wildlife use in meadows of the northern Black Hills.

KEY WORDS cattle, grazing, range, standing crop, vegetation, visual obstruction, wildlife.

Ponderosa pine (*Pinus ponderosa)* dominates the native vegetation of most Black Hills forests (Pase and Thilenius 1968, Severson and Boldt 1977, Hoffman and Alexander 1987). Interspersed meadows represent a relatively small portion (approximately 3%) of the northern Black Hills National Forest, but are important for wildlife and livestock (Uresk et al. 1999). Meadows are primarily used for livestock grazing, but annual measurements are seldom collected to determine use or available vegetation for wildlife. Also, public interest in management of meadows and livestock use on public lands is being displaced by an interest in recreational activities (Brooks and Champ 2006, Bengston et al. 2004). A practical monitoring technique that quantifies standing herbage on meadow lands is limited in the northern Black Hills.

Monitoring standing herbage is a common method for managing livestock grazing, wildlife habitat, and plant diversity (Bement 1969, Heady and Child 1994). However, direct herbage measurements are time consuming, expensive, and may delay resource decisions. The Robel pole is a tool used to estimate standing herbage by visual obstruction readings (VORs). It has received considerable attention in the literature (Robel et al. 1970, Volesky et al. 1999, Benkobi et al. 2000, Vermeire and Gillen 2001). Once the relationship between VORs and standing herbage has been established, the Robel pole provides a simple, quick, and reliable tool to estimate standing herbage. Originally the pole was graduated in decimeters (Robel et al. 1970). Benkobi et al. (2000) modified the pole using one-inch (2.54 cm) bands. However, for monitoring short vegetation or heavily grazed areas including xeric sites, decimeter or 2.54 cm bands are imprecise. To monitor short vegetation or heavily grazed areas adequately, we employed a pole with 1.27 cm bands (Uresk and Benzon 2007, Uresk and Juntti 2008).

Our objectives were to quantify the relationship between standing herbage and VORs, determine sample size estimates (number of transects) required to achieve adequate precision for monitoring, and develop guidelines for monitoring meadows in the northern Black Hills based on 1.27 cm Robel pole bands.

STUDY AREA

Our study was conducted in the northern Black Hills in Lawrence and Pennington counties, South Dakota. The area included forested lands north of a line one mile south of the Pennington County north boundary line. This south project boundary line extends west from Interstate highway 90 near Blackhawk, South Dakota through Rochford, South Dakota to the Wyoming state line. The area is characterized by stands of ponderosa pine interspersed with meadows, parks, and other openings. Average annual precipitation varied from 41 to 56 cm (Orr, 1959) and most precipitation occurred in May and June. Precipitation recorded during January through August 2008 in Lead, South Dakota (the approximate center of the study area) was 29.3 cm greater than the long-term average over 99 years (High Plains Regional Climate Center 2008). Temperatures during the growing season (April through September) ranged from 6.6 to 22.2° C (Orr 1959). The annual growing season ranged from 97 to 154 days and elevation ranged from 1067 to 2153 m. Plant species

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composition and diversity were described by Thilenius (1972) and Hoffman and Alexander (1987). Estimated peak standing herbage of vegetation in meadows ranged from 1170 to 2930 $kg \cdot ha^{-1}$ (Thomas et al. 1964, Pase and Thilenius 1968). Common plant species included: Kentucky bluegrass (*Poa pratensis)*, timothy (*Phleum pretense)*, smooth brome *(Bromus inermis)*, sedges (*Carex* spp.*)*, western wheatgrass (*Pascopyrum smithii)*, prairie dropseed (*Sporobolus heterolepis)*, fleabane (*Erigeron* spp.) and yarrow (*Achillea* spp.).

METHODS

We sampled meadow sites from the foothills to higher elevations throughout the northern Black Hills in 2008. We sampled visual obstruction (number of 1.27 cm bands) and clipped herbage from late June through mid September following the procedures described by Uresk and Benzon (2007). We numbered bands beginning with zero for the first band at the bottom of the pole. We observed visual obstruction readings from a distance of 4 m with the reader's eye at a height of 1 m. The lowest visible band not obscured by the vegetation on the pole was recorded. We recorded at each station a VOR in each of 4 cardinal directions for a transect total of 80 VORs. We used a stratified sampling design to collect data (Benkobi et al. 2000, and Uresk and Benzon 2007) along 123 transects representing a range of vegetation VORs from short, intermediate, and tall vegetation based on preliminary inspection of vertical heights. We recorded coordinates with GPS for randomly located transects among the 3 strata within meadows large enough to include a 200 m transect. Livestock grazed the meadows from spring to late fall; some meadows were excluded from livestock as part of management. Wildlife grazed the meadows throughout the year.

Along each 200 m transect, we recorded VORs at 20 stations spaced 10 m apart. We clipped standing herbage within a 0.25 m^2 circular hoop located and centered on stations at 0, 50, 100, and 150 m. Additionally we clipped all vegetation within a hoop at ground level, oven dried it at 60° C for 48 hours, and weighed it to the nearest 0.1 gram. Standing herbage is expressed as $kg \cdot ha^{-1}$.

We averaged VORs and clipped herbage for all 123 transects. We analyzed relationships between VORs and herbage using linear regression (Stastical Package Social Sciences 2003) and cluster analysis (ISODATA) to create management resource groupings with minimum variances (short, intermediate and tall) based on VORs and $kg \cdot ha^{-1}$ data (Ball and Hall 1967, del Morel 1975). We standardized data (VOR and $kg \cdot ha^{-1}$) to give variables equal weight in the analyses (individual data subtracted from the sample mean/standard deviation). We estimated the number of transects needed to achieve estimates within 20% of the mean with an 80% confidence level.

RESULTS

Clipped herbage ranged from 140 to 3313 $kg \cdot ha^{-1}$ on grazed and ungrazed meadows with a mean of 1386 $kg \cdot ha^{-1}$. Transect VORs ranged from 0.6 to 30.4 with a mean of 10.9. The relationship between standing herbage and VORs was strongly linear (Fig. 1). The slope from the regression model was 73 $kg \cdot ha^{-1}$ / band with an intercept of 587 $kg \cdot ha^{-1}$. Our regression result was significant ($R^2 = 0.80$, $P < 0.001$) and is considered high for this type of field study.

Cluster analysis of VORs with $kg \cdot ha^{-1}$ resulted in three distinct minimum variance groups. The 3 resource groupings were short, intermediate, and tall (Table 1). They also represent heavy, moderate and light to no grazing (Holechek et al. 1989, Heady and Child 1994). Based on the variance of the 3 groupings, to achieve a precision of 20% of the mean with 80% confidence would require 4 transects per section (259 hectares) of meadows.

DISCUSSION

Relationships we described between VORs and standing herbage weight represented meadows throughout the northern Black Hills. We sampled over a broad range of conditions from no grazing to grazing throughout the growing season. We used our data over this range of conditions to define guidelines for resource management. These guidelines were based on data from this study and on results from Thomas et al. (1964) and Pase and Thilenius (1968). Overall mean herbage of their two studies was approximately 2050 $kg \cdot ha^{-1}$ for peak standing herbage, compared to mean of 2218 $kg \cdot ha^{-1}$ for the tall category in our study. We considered this the mean herbage potential of the area. Monitoring vegetation for residual herbage throughout the growing season in our study was based on our 2218 $kg \cdot ha^{-1}$, an average potential for meadows in the northern Black Hills. For instance, considering a management objective of 40, 50, and 60% livestock use of the average herbage potential, residual standing herbages would be represented by VORs of approximately 10, 7, and 4, respectively.

Most management of livestock on rangelands, including mountain meadows, is based on forage utilization (NAS-NRC 1962, Holechek et al. 1989, Heady and Child 1994). Utilization is difficult to measure with a high degree of accuracy and is often estimated by ocular observations or by clipping herbage in and out of utilization cages. Clipping herbage is expensive and time consuming (NAS-NRC 1962, Holechek et al. 1989, Heady and Child 1994). Percent utilization of forage is a variable that fluctuates annually, thus a band and VOR objective for leaving the same amount of standing herbage for wet and dry years is recommended. Managers can use VOR-based monitoring to prevent residual vegetation overgrazing and subsequent damage to vegetation and other resources. Otherwise, additional grazing would provide inadequate residual herbage to sustain or increase plant productivity and improve the quality of meadows.

Transition from monitoring percent utilization to standing herbage is more precise and less time consuming. Our results suggest a VOR of 10 (1330 kg·ha^{-1} residual herbage remaining at 40% use) would enable resource managers to achieve most livestock management objectives of maintaining or improving vegetation in the northern Black Hills. Further, this recommended objective of band 10 would remain constant during wet and dry years. When a VOR of 10 is measured in the field, livestock removal from allotment is warranted. Reduced grazing periods and livestock stocking densities are recommended in dry years whereas greater livestock grazing (more days or more animals) may be possible during growing seasons in years of above average precipitation.

Table 1. Categories defined by cluster analysis for short, intermediate, and tall vegetation with VOR band number on a modified Robel pole (1.27 cm wide bands). Corresponding kg·ha^{-1} is based on VOR band-weight equation in the northern Black Hills, South Dakota, 2008. VOR band number represents visual obstruction reading.

Category (Number of Transects)	VOR Band kg·ha^{-1}	Minimum	Mean	Maximum
Short (49)	Band	0.6	2.6	6.3
	kg·ha^{-1}	631	778	1050
Intermediate (37)	Band	6.4	10.4	16.2
	kg·ha^{-1}	1057	1351	1777
Tall (37)	Band	16.3	22.2	30+
	kg·ha^{-1}	1785	2218	2791

Three resource categories were determined based on results of cluster analysis (Table 1) for management of livestock and wildlife grazing, wildlife use, and monitoring guidelines. Guidelines are useful throughout the northern Black Hills and can be used to meet management objectives (grazing and wildlife) for each allotment. The three VOR categories (short, intermediate, and tall) represented meadows heavily, moderately to lightly, or ungrazed based on VOR bands and standing herbage. These categories would provide resource managers with guidelines to maintain current management or change management objectives to achieve desired results. We recommend 4 transects be sampled to determine differences among 3 categories and that variance of 4 transects be used to characterize an entire allotment with sampling in each section (259 ha). If the objective is to manage for specific herbage (i.e., VOR) to remove livestock, a 1-sided *t*–test is appropriate using the variance of four transects. For example, if a VOR of band 10 is the desired objective for removal of livestock, the 1-sided *t*-test at α =0.05 (Uresk and Juntti 2008) is recommended to test for differences from a VOR of 10.

A 40% use of the potential (Band 10) is generally considered the standard for light grazing at which livestock should be removed to maintain a healthy or improved rangeland (Holechek et al. 1989, Heady and Child 1994). In key wildlife areas, leaving more standing herbage may be warranted (Uresk et al. 1999), and in some areas less herbage may be beneficial (Frisina 1992, Shepperd and Battaglia 2002, Martin and Possingham 2005). Approximately 10–15% in the short and tall categories is recommended for resource management (Mueller-Dombois and Ellenberg 1974). This provides a full range of herbage values on the landscape for the northern Black Hills (Uresk and Benzon 2007).

A comparison of standing herbage remaining after livestock grazing (40% use) was similar for both the central (1419 kg·ha^{-1}; Uresk and Benzon 2007) and northern Black Hills (1330 kg·ha^{-1}; present study), despite differences in regional VORs. For an approximate 40% use, a VOR of 5 is the recommended minimum for livestock removal in the central Black Hills (Uresk and Benzon 2007), whereas a VOR of 10 is required in the northern Black Hills. Regional differences are largely explained by relationships between VORs and clipped herbage by transects. The central Black Hills has a curvilinear relationship while the northern Black Hills has a linear relationship. The linear relationship between VORs and standing herbage for the northern Black Hills may be associated with additional timothy and smooth brome in regional plant communities. These two plant species contribute less herbage weight per VOR band; thus a higher VOR is required in the northern Black Hills to achieve a similar weight in the central Black Hills.

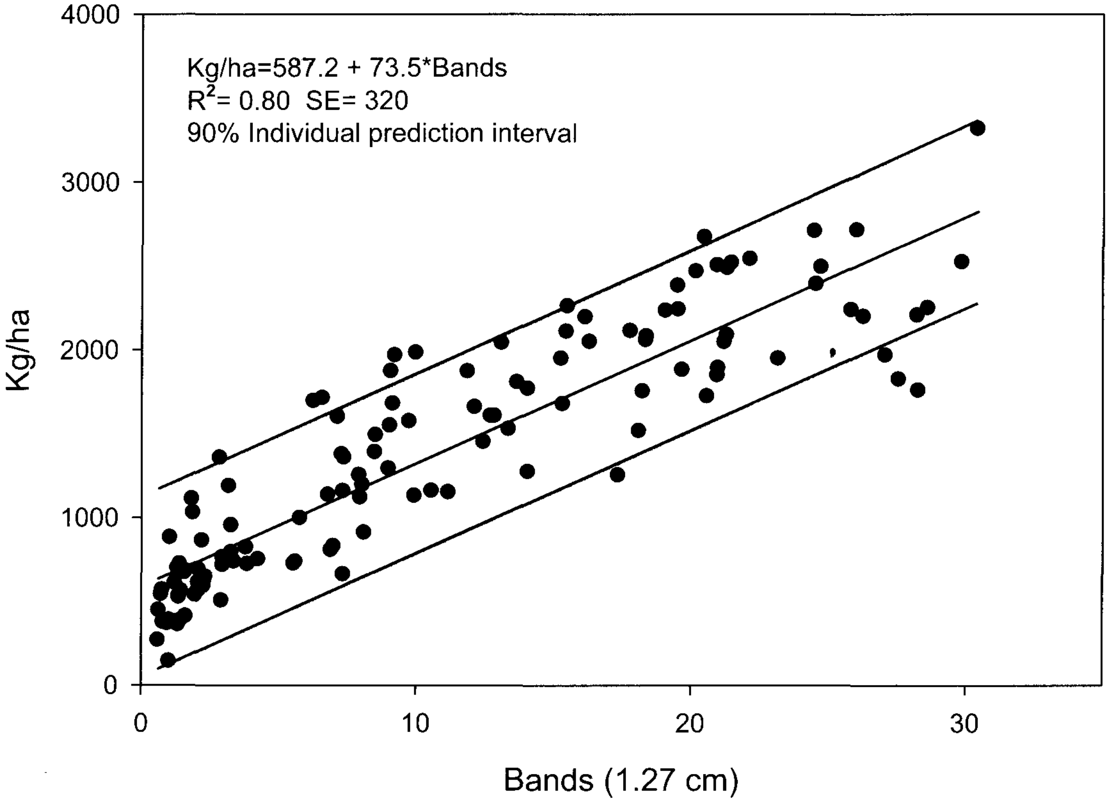

Figure 1. Regression relationship between Visual Obstruction Reading (VOR) bands and herbage (kg·ha^{-1}) with 90% prediction bands for individual transects on the northern Black Hills, South Dakota, 2008.

MANAGEMENT IMPLICATIONS

The modified Robel pole calibrated for the northern Black Hills provides for resource managers, a rapid cost effective measurement for establishment of guidelines to leave a desired amount of residual vegetation concerning grazing use and wildlife needs. Guidelines to leave standing herbage by removal of livestock at bands 10 and 7 would maintain proper structure to improve the resources, increase plant diversity, improve herbage production and reduce non-point source pollution by reducing sediment movement. Monitoring vegetation structure for grazing may be implemented from peak standing herbage to early frost and adjustment of livestock numbers and duration of grazing will meet resource objectives. Management of short, intermediate and tall vegetation structure in the meadows provides diversity of herbage left ungrazed with a high degree of accuracy and precision.

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