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# Monitoring mid-grass prairie in southwestern South Dakota and northwestern Nebraska, USA

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## Abstract

It is expensive and difficult to make precise measurements of standing herbage and to monitor changes in rangeland pastures. This study used a modified Robel pole with 1.27-cm alternating white and gray bands to estimate standing herbage on adjacent Buffalo Gap and Oglala National Grasslands in western South Dakota and northwestern Nebraska. We determined the relationship between visual obstruction readings (Robel pole) with clipped standing herbage and developed resource guidelines for monitoring standing herbage. Clipped standing herbage ranged from 72 to 4953 kg dry matter (DM) ha$^{-1}$ with a mean of 1784 kg DM ha$^{-1}$. Visual obstruction bands (band = 1.27 cm) averaged 6.9 bands and ranged from 0.1 to 22.9. Visual obstruction reliably predicted standing herbage ($R^2$ = 0.80, $P$ = 0.001, SE = 485 kg DM ha$^{-1}$, $n$ = 182 transects). Cluster analyses grouped visual obstruction readings (bands) and standing herbage into three resource categories; short, intermediate and tall. Band 6 corresponds to residual standing herbage of 1626 kg DM ha$^{-1}$ and is recommended as a monitoring guideline for minimum residual herbage. Monitoring of residual standing herbage is accurate, precise and easy to apply. The monitoring protocol and guidelines developed based on bands and/or standing herbage provide information for managers to determine compliance with desired plans to maintain diversity for plants, wildlife and livestock use that sustain grassland communities.

## Introduction

Monitoring annual herbage use on rangelands by direct clipping measurements is problematic due to the difficulty and expense of obtaining an adequate sample size of sufficient precision. To meet the increasing demand for intensive monitoring of vegetation for livestock grazing and wildlife habitat on public rangelands, the modified Robel pole is an improved, accurate and cost-effective methodology (Benkobi *et al.* 2000; Uresk and Benzon 2007; Uresk *et al.* 2010). The use of the Robel pole for monitoring has received considerable attention in the published work (Robel *et al.* 1970; Volesky *et al.* 1999; Vermeire and Gillen 2001; Higgins *et al.* 2005). Once the relationship between visual readings and standing herbage (standing live and dead vegetation) has been calibrated, the modified Robel pole provides a quick, simple, accurate, precise and cost-effective tool to estimate standing herbage (Benkobi *et al.* 2000). Other methods have used variations of visual estimates for vegetation measurements that are highly variable among observers (Schultz *et al.* 1961; Kershaw 1973; Block *et al.* 1987; Irving *et al.* 1995). The advantage of using techniques that have been calibrated to actual measurements (i.e. clipping vegetation) is that they are more accurate than widely used ocular estimates (Bonham 1989).

The modified Robel pole uses a visual obstruction reading (VOR) that is a combined height density measurement of vegetation for monitoring residual standing herbage. Tall, widely spaced vegetation will have a low VOR. This same tall vegetation with greater amounts of leaf mass (density) will have a higher VOR. Thus, VOR measurements are greatly dependent upon height and density of the vegetation. Resource guidelines established from VOR estimates of standing herbage to maintain healthy rangelands are widely used to sustain the natural prairie grasslands (Bement 1969; Holechek *et al.* 1989; Heady and Child 1994; Mergen *et al.* 2001; Molinar *et al.* 2001). The objectives of this study were to: (i) develop the relationship between VOR and standing herbage; (ii) develop sample size estimates for number of transects required to achieve adequate precision for monitoring; (iii) develop guidelines for monitoring; and (iv) validate the developed model for estimating standing herbage on mid-grass prairie range sites.

## Materials and methods

### Study area

The study area comprising natural prairie grasslands was located on the Buffalo Gap and Oglala National Grasslands in western South Dakota and northwestern Nebraska. This broad geographic area includes grasslands west and east of Wall, South Dakota, to southwest of Edgemont, South Dakota, and non-forested areas of the Oglala National Grassland in northwestern Nebraska. The semiarid continental climate is characterized based on average daily temperatures by cold winters (December to February −5°C) and warm summers (June to August 22°C). Average annual precipitation (101–117 years) is 40.4 cm at Cottonwood and 43.8 cm at Oelrichs, South Dakota (High Plains Regional Climate Center 2011a,b). Most precipitation occurs as rain during the growing season (April–September) and snow during the winter months. At Cottonwood, annual precipitation in 2008 and 2009 was 57.0 and 43.5 cm, respectively. No annual precipitation data were reported from Oelrichs for these years.

Cattle are the primary herbivores grazing on the grasslands, ranging in fall weights of individual cows ($n$ = 874 cows) from 445–862 kg with an average of 598 kg (Fort Pierre Livestock Auction, 2012) and some American bison (*Bison bison*) also graze on these pastures. The number of cattle grazing will vary depending primarily upon soil moisture conditions. Wildlife grazing the area include American antelope (*Antilocapra americana*), mule deer (*Odocoileus hemionus*) and white-tailed deer (*Odocoileus virginianus*).

This study is within the western wheatgrass–blue grama –buffalograss ecological type (Kuchler 1975). Dominant grasses are western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Love), blue grama (*Bouteloua gracilis* [Willd. Ex. Kunth] Lag. Ex. Griffiths), buffalograss (*Bouteloua dactyloides* [Nutt.] J. T. Columbus), green needlegrass (*Nassella viridula* [Trin.] Barkworth) and needleleaf sedge (*Carex duriuscula* C.A. Mey.). Common forbs are scarlet globemallow (*Sphaeralcea coccinea* [Nutt.] Rydb.), bigbract verbena (*Verbena bracteata* Cav. ex Lag. and Rodr.) and woolly plantain (*Plantago patagonica* Jacq.) (Uresk 1990). Plant nomenclature follows USDA NRCS (2011). Soil textures are clayey and include dense clay, thin upland, clayey overflow and shallow clayey and are within the major land resource areas 60A (USDA NRCS 2008).

Livestock grazing is common throughout the study area and several studies have reported on peak standing herbage. Uresk (1990) and Uresk and Paulson (1988) estimated peak standing herbage expressed as dry matter (DM) in Conata Basin, South Dakota at 2492 kg DM ha$^{-1}$ and 2267 kg DM ha$^{-1}$, respectively. Lewis *et al.* (1956) reported a 3-year average (1952–1955) under light grazing at Cottonwood, South Dakota at 3299 kg DM ha$^{-1}$ while Johnson *et al.* (1951) reported a 9-year average (1942–1950) of 2293 kg DM ha$^{-1}$. USDA NRCS (2008) reported an average of 3138 kg DM ha$^{-1}$ on clayey rangeland during above average precipitation and 2242 kg DM ha$^{-1}$ for average years.

### Methods

We sampled throughout the Buffalo Gap and Oglala National Grasslands and adjacent lands encompassing approximately 280 000 ha in 2009. Grasslands were sampled from early July near peak standing herbage, to early October on ungrazed to heavily grazed pastures. All procedures and methods followed Robel *et al.* (1970), Uresk and Benzon (2007), and Uresk *et al.* (2010). A modified 2.54-cm diameter Robel pole was painted with alternating 1.27-cm white and gray bands. Bands were numbered beginning with 0 at the bottom band which was placed on the soil surface. A VOR was made at a distance of 4 m from the station with the reader's eyes at a height of 1 m. The lowest visible band was recorded and if band 0 was visible, it was recorded as 0.

A stratified random design was used to collect 182 transects from three grasslands strata, short, medium and tall vegetation, to sample the full range of vegetation (Cochran 1977; Thompson *et al.* 1998; Levy and Lemeshow 1999). Strata are independent of resource groupings defined by cluster analyses. Transects were located randomly within each stratum throughout the study area. Global Positioning System coordinates and compass bearings were recorded at the beginning of each transect. An additional 30 transects were collected throughout the 2010 growing season for validation of the model.

Visual obstruction readings were recorded at 20 stations spaced at 10-m intervals along 200 m transects. At each station, four VOR were recorded at 90° intervals. From within each transect, we clipped standing herbage at four stations (50, 100, 150 and 200 m) within a

 

0.25-m$^2$ hoop to ground level. All vegetation was oven-dried at 60°C for 48 h and weighed to the nearest 0.1 g. Standing herbage was expressed as kg DM ha$^{-1}$.

Data for all VOR and clipped herbage were averaged by transect for data analyses and sampling was spread over the growing season on grazed and ungrazed pastures. We used linear regression (SPSS, Chicago, IL, USA, 2003; $n$ = 182 transects) for model development of the relationship between standing herbage and VOR. Non-hierarchical cluster analysis (ISODATA) was used to develop resource groupings for guidelines to evaluate grazing, wildlife habitat and drought conditions for allotments and pastures (Ball and Hall 1967; del Morel 1975). Regression models alone will not provide complete guidelines for resource management. We standardized VOR and kg DM ha$^{-1}$ to give equal weight in the analysis for the variables (individual data subtracted from the sample mean/standard deviation). Cluster analyses for 162 transects were used for development of resource groupings and guidelines based on minimum variances within a cluster. Clusters are unsupervised and are defined by the ISODATA algorithm. Twenty transects within the 182 total collected had extremely high standing herbage DM during an exceptionally wet year. These 20 transects were not considered for development of resource guidelines, however, means and ranges are presented. Historically, these amounts have never been reported. The 162 transects were within the range of herbage values (kg DM ha$^{-1}$) based on historical research studies within or near the study area. The number of transects to achieve estimates within 20% of the mean with an 80% confidence level were evaluated based on the regression variance. Validation data collected in 2010 for model testing were evaluated at the 90% individual prediction interval and for outliers that deviated by three standard deviations or greater.

## Results

Visual obstruction readings from 182 transects ranged from 0.1 to 22.9 bands with an overall mean of 6.9 (Figure 1). Clipped, oven-dried standing herbage, ranged from 72 to 4953 kg DM ha$^{-1}$ with a mean of 1784 kg DM ha$^{-1}$. Data showed a strong linear relationship between standing herbage and VOR ($R^2$ = 0.80, $P$ = 0.001, SE = 485 kg DM ha$^{-1}$, $n$ = 182 transects). Residuals were normally distributed based on probability plots.

Cluster analyses (ISODATA) of all 182 transects (standardized VOR and standing herbage DM ha$^{-1}$) identified a group of 20 transects with extremely high amounts of vegetation. VOR and clipped herbage for this group ranged from 12.8 to 22.9 bands with a mean of 16.7 bands; standing herbage ranged from 2890 to 4953 kg DM ha$^{-1}$ with a mean of 3831 kg DM ha$^{-1}$. Cluster analyses on the remaining 162 transects resulted in three distinct categories for long-term resource management that coincides with the range of historical research values (Table 1). The categories are short (0.1–3.9 bands), intermediate (4.0–9.1 bands) and tall (9.2–17.4 bands). Standing herbage derived from the regression model ranged from 594 to 1363, 1381–2168 and 2186–3620 kg DM ha$^{-1}$ for short, intermediate and tall categories, respectively. VOR at band 17.4 (maximum VOR) had an estimated weight of 3620 kg DM ha$^{-1}$.

Validation of the model (Figure 1) showed that prediction of standing herbage was excellent as expected when

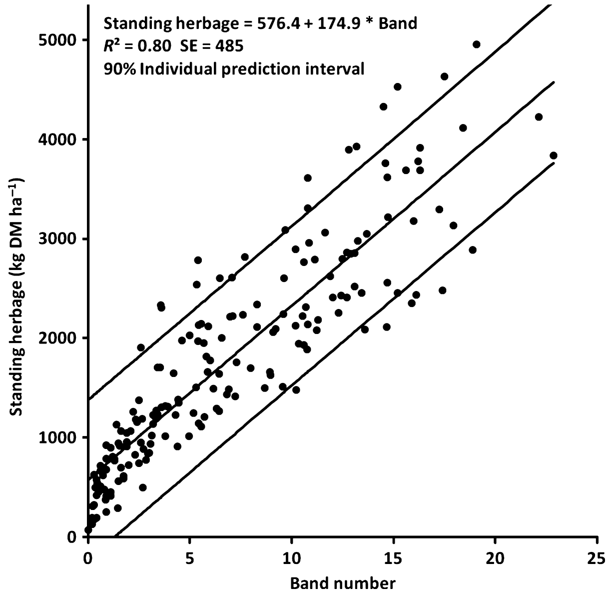


**Figure 1** Regression relationship between the standing herbage and the lowest visible pole band number (visual obstruction readings; band height = 1.27 cm) with 90% individual prediction intervals. DM, dry matter.

**Table 1** Resource categories for short, intermediate and tall by band number (1.27 cm, 0.5 inch) on a Robel pole with corresponding standing herbage (kg DM ha$^{-1}$) value (categories defined by cluster analysis for 162 transects)

| Category | Attribute | Minimum | Mean | Maximum |
|---|---|---|---|---|
| Short ($n$ = 73)† | Band number‡ | 0.1 | 1.8 | 3.9 |
| | Standing herbage§ | 594 | 891 | 1259 |
| Intermediate ($n$ = 49) | Band number | 4.0 | 6.3 | 9.1 |
| | Standing herbage | 1276 | 1678 | 2168 |
| Tall ($n$ = 40) | Band number | 9.2 | 12.1 | 17.4 |
| | Standing herbage | 2186 | 2693 | 3620 |

†Number of transects.
‡The lowest visible pole band number (visual obstruction readings; band height = 1.27 cm).
§Based on the band-weight equation in Figure 1. DM, dry matter.


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**Table 2** Validation of the model (Figure 1) for 30 sites during the second year of sampling

| Site | Band number† | Standing herbage (kg DM ha$^{-1}$)‡ | LL§ | UL§ |
|---|---|---|---|---|
| 1 | 0.8 | 432 | −107 | 1513 |
| 2 | 1.0 | 392 | −72 | 1547 |
| 3 | 1.3 | 456 | −20 | 1599 |
| 4 | 1.5 | 784 | 15 | 1634 |
| 5 | 2.4 | 764 | 172 | 1790 |
| 6 | 2.7 | 1036 | 225 | 1842 |
| 7 | 3.2 | 1068 | 312 | 1929 |
| 8 | 4.0 | 892 | 452 | 2068 |
| 9 | 4.5 | 2136 | 539 | 2155 |
| 10 | 5.0 | 1208 | 626 | 2242 |
| 11 | 5.5 | 1764 | 713 | 2329 |
| 12 | 5.5 | 844 | 713 | 2329 |
| 13 | 6.3 | 1512 | 853 | 2468 |
| 14 | 7.1 | 1188 | 992 | 2607 |
| 15 | 7.5 | 1628 | 1062 | 2677 |
| 16 | 7.7 | 3040¶ | 1096 | 2712 |
| 17 | 7.9 | 1844 | 1116 | 2748 |
| 18 | 9.1 | 1776 | 1340 | 2956 |
| 19 | 9.2 | 1928 | 1357 | 2973 |
| 20 | 9.3 | 1536 | 1375 | 2991 |
| 21 | 9.5 | 2108 | 1409 | 3025 |
| 22 | 9.9 | 2988 | 1479 | 3095 |
| 23 | 9.9 | 1704 | 1479 | 3095 |
| 24 | 11.4 | 1316¶ | 1721 | 3355 |
| 25 | 12.3 | 2988 | 1876 | 3512 |
| 26 | 13.8 | 3820¶ | 2155 | 3777 |
| 27 | 14.1 | 2980 | 2207 | 3829 |
| 28 | 15.0 | 2460 | 2363 | 3987 |
| 29 | 16.3 | 2592 | 2588 | 4215 |
| 30 | 16.6 | 3128 | 2640 | 4267 |

†The lowest visible pole band number (visual obstruction readings; band height = 1.27 cm).
‡Measured value.
§LL and UL, lower and upper prediction limits for 90% probability, respectively.
¶Sites outside the prediction limits. No extreme outlier's >3 standard deviations were detected, and 90% of the sites (27 sites) were positioned within the limits of the model. DM, dry matter.

sampling was confined to this ecological type (Table 2). A total of 27 transects (90%), collected the following growing season, from no grazing to heavy grazing, fell within the 90% prediction limits. Five transects are required to achieve estimates within 20% of the mean with 80% confidence for monitoring key areas defined by managers of 259 ha or less (Benkobi *et al.* 2000) based on the regression variance for standing herbage and VOR.

## Discussion

Monitoring livestock use of rangelands is generally based on annual utilization of forage (NAS NRC 1962; Holechek *et al.* 1989; Heady and Child 1994). A fixed amount of forage based on the current year's estimated peak standing herbage, is allocated each year for livestock grazing. The residual herbage at the end of the grazing season varies from year to year. In wet years, more standing herbage is left and in dry years less. The former case is uneconomical and the latter inconsistent with protection of the resource when based on percent utilization. We used 2693 kg DM ha$^{-1}$, the mean of the tall category (Table 1), as representative of the mean annual standing herbage potential. With VOR-based monitoring (herbage left ungrazed), a fixed amount of residual standing herbage at band 6, approximating 40% of potential yield, should be maintained regardless of annual variation in peak standing herbage. Thus, in dry years, negative impacts of overgrazing vegetation will be minimal or avoided and, in wet years, economic return will be maximized.

Maintaining an adequate amount of residual herbage at the end of a grazing season is important for early spring growth and preventing water erosion at the start of the next season (Beetle *et al.* 1961; Molinar *et al.* 2001). This results in cooler soil for a longer period of plant growth, more soil water storage with less run-off and sediment yield, and later maturation with greater plant production overall. In addition, maintaining adequate residual vegetation greatly reduces wind speed and sheer at the soil surface, thereby reducing wind erosion and soil water evaporation (Lal 1994).

Direct measurement of forage utilization is difficult. Commonly, forage is clipped inside and outside exclosures or cages that prevent livestock grazing. The process is time-consuming, expensive and difficult to achieve with adequate replication. Indirect methods, such as the widely used ocular method, avoid these difficulties but suffer from inaccuracy and observer bias (Schultz *et al.* 1961; Kershaw 1973; Block *et al.* 1987; Irving *et al.* 1995). The Robel pole overcomes the drawbacks of both direct and subjective indirect methods. Standing herbage for 20 transects had a mean of 3831 kg DM ha$^{-1}$ with extremely high values ranging 2890–4953 kg DM ha$^{-1}$. These high data values exceed information published for past years (Johnson *et al.* 1951; Lewis *et al.* 1956; Uresk and Paulson 1988; Uresk 1990; USDA NRCS 2008). Mean precipitation at Cottonwood, South Dakota in 2008 was 41% above the long-term average. In 2009, when the study was conducted, precipitation was 8% above the average. A complete summary of precipitation at Oelrichs, South Dakota for 2008 and 2009 was not available. Soil moisture was above average in 2008 and was followed by greater than average precipitation in 2009 that resulted in extremely high standing herbage values. The overall guidelines including Table 1 for resource management were based on long-term standing herbage from published results. Average peak standing herbage from five studies was 2519 kg DM ha$^{-1}$ (Johnson *et al.* 1951; Lewis *et al.* 1956; Uresk and Paulson 1988; Uresk 1990; USDA NRCS 2008). In our study based on 162 transects for cluster analyses, the average standing herbage for the tall category was estimated at 2693 kg DM ha$^{-1}$ for the study area of 280 000 ha. We consider this the long-term average potential of standing herbage. Grazing a pasture to a level of 6.0 VOR bands (leaving 1626 kg DM ha$^{-1}$ standing herbage) corresponds to approximately 40% utilization in an average growth year for total standing herbage, and we recommend this as a guideline for minimum residual vegetation. Resource managers adopting band 6 will more readily achieve the objectives of maintaining or improving the vegetation on both National Grasslands and adjacent prairie despite variations in annual precipitation (Hooper and Heady 1970; Holechek *et al.* 1989; Heady and Child 1994; Mergen *et al.* 2001). When band 6 is measured in the field, livestock removal from the pasture or allotment is warranted to prevent residual vegetation from being reduced to a point where the pasture resource is damaged. Shorter grazing periods and reduced livestock numbers are recommended in dry years while in wet years a longer duration of grazing or greater number of livestock is possible.

The three categories (short, intermediate and tall) identified by cluster analysis (Table 1) correspond to heavy, moderate and light to no grazing intensities primarily on clayey sites but the same vegetation may extend across other soil types. These categories may be partially dependent upon system of grazing. For management of wildlife habitat, the desired category may differ from that preferred for livestock production. In key grouse nesting habitats it may be prudent to manage at band 7 (>3.4 inches) for residual standing herbage (Prose *et al.* 2002). However, to maintain black-tailed prairie dog colonies, with limited or no expansion, band 5 is recommended regardless of plant species composition, based on the midpoint VOR from Severson and Plumb (1998). Less than band 5 is recommended for expansion of black-tailed prairie dog colonies. Thus, livestock should be removed at band 5 for maintenance of prairie dog colonies. Approximately 10–15% of the landscape in short and tall categories and the remainder in the intermediate category are recommended for successful resource management (Kershaw 1973; Mueller-Dombois and Ellenberg 1974). These categories may vary spatially over the landscape with time. This provides a full range of values on the landscape to maintain plant and wildlife diversity (Uresk 1990; Rumble and Gobeille 1998; Fritcher *et al.* 2004; Benkobi *et al.* 2007).

Validation of the developed model was as predicted, with 90% of transects falling within the 90% prediction limits. There were no extreme outliers of three standard deviations or greater. The model underestimated two sites and overestimated one site outside the 90% prediction limits.

Future, independent sampling with an unknown variance requires five transects to achieve reliability and precision at 80% confidence of being within 20% of the mean for standing herbage. We used the regression variance to estimate the number of transects required to characterize a section of land (259 ha, 1 mile$^2$) or key area as defined by Holechek *et al.* (1989). If the objective is to manage for a specific VOR for removing livestock, a one-sided Student's *t*-test is appropriate using the variance of the five transects. For example, if a VOR of band 6 warrants the desired removal of livestock, then the one-sided Student's *t*-test ($\alpha = 0.05$) is appropriate to test for differences less than the established guideline of band 6 (Steel and Torrie 1980; Uresk and Benzon 2007; Uresk *et al.* 2010). At the landscape level, monitoring efficiency is related to size of the land base (figure 5 in Benkobi *et al.* 2000). For example, at 16 000 ha (39 539 acres), a 10% sample is recommended. A 16 000 ha area has 62 sections (62 miles$^2$) or 248 quarter sections, so 24 transects would meet the 10% requirement. The area to be sampled should be stratified with a minimum of three strata over the selected landscape to ensure transects are well distributed. Eight sections would be randomly selected within each of the three strata. One randomly located transect would be sampled in a randomly selected quarter section. This option will produce a more precise overall estimate of average VOR within the 16 000 ha. The alternative would be to sample 6 randomly located sections with five transects per section. This would require a greater amount of effort to attain the same level of precision. Landscape stratification may also be defined for ungrazed or heavily grazed pastures only, or all vegetation conditions for an overall assessment that meet the above requirements.

Monitoring vegetation with the developed model in this study and other modified Robel pole studies require several constraints. These include staying with the ecological type described in this paper because the type may expand over into soils other than clayey. Sampling outside the ecological type could produce spurious results. The model was developed with upright standing vegetation; however, taller vegetation subjected to heavy rain, high winds or hail, and late maturing vegetation may naturally bend over resulting in prediction errors of standing herbage mass that are beyond model constraints. Early frost and snow will also lodge the vegetation and often produce erroneous results after melt.

## Conclusion

Visual obstruction readings and clipped vegetation were collected over a large geographic area, Buffalo Gap and


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Oglala National Grasslands, and adjacent grasslands in western South Dakota and northwestern Nebraska, from peak standing herbage to early frost. The recommended band 6 guideline for total residual standing herbage after livestock grazing would maintain adequate residual standing herbage mass and structure to improve the natural resource and herbage production for livestock. Diversity of plants and wildlife resources will require 10–15% of the landscape in short and tall categories with the remainder in the intermediate category. The categories are similar to heavy, moderate and light-to-no grazing. Appropriate VOR standards can be established to maintain this diversity throughout the landscape. Adjustment of livestock numbers and duration of grazing can be implemented throughout this period to meet resource objectives. Resource management by short, intermediate and tall VOR categories provides the diversity of structure required to maintain a diversity of plants and wildlife with continued livestock use to sustain a healthy prairie. The calibrated Robel pole will provide information for resource managers to determine compliance with desired plans for vegetation conditions and to implement guidelines.

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