BIOLOGICAL CAPABILITIES OF SELECTED ECOLOGICAL SITES IN THE WESTERN DAKOTAS

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Dustin Ford

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Biological Capabilities of Selected Ecological Sites in the Western Dakotas

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Kevin K. Sedivec
Chair

Edward DeKeyser

Benjamin Geaumont

Jack Norland

Approved:

7/23/14
Date

Frank X.M. Casey
Department Chair

ABSTRACT

The study was conducted on the Dakota Prairie National Grasslands (DPG) within the Little Missouri National Grassland (LMNG) of North Dakota and Grand River National Grassland (GRNG) of South Dakota during the summer and fall of 2012. The objectives of this study was to 1) determine if three ecological sites (loamy, thin loamy, and claypan) are biologically capable of producing an 8.89 cm visual obstruction reading (VOR) at the end of the grazing season when cattle are excluded and 2) establish a relationship between VOR and standing crop. Vegetative structure was determined using a modified Robel pole. Standing crop was collected by clipping to ground level using a $0.178m^2$ hoop. Based on our results from one year of data, only the loamy sites on the LMNG were biologically capable of producing 8.89 cm of structure at the end of the grazing season in the DPG.

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INTRODUCTION

Vegetation on the National Grasslands provides a valuable resource for people, livestock and wildlife in the western Dakotas. A diverse composition of native plant species allows for a properly functioning ecosystem. The proper management of rangelands in the Dakota Prairie National Grasslands (DPG) is essential in sustaining livestock production and critical wildlife habitat. The ability of land managers to properly manage public lands largely depends on their ability to assess current and past conditions of the rangelands. The Robel pole was developed to assess the visual obstruction of the structure as a height to density measurement for wildlife habitat (Robel et al. 1970). Clipping is a common method for determining biomass production on pastures and rangelands (Milner and Hughes 1968). Clipping is often considered the most effective method of determining species composition and overall production, however, clipping is a time consuming technique that requires knowledgeable personnel. While visual obstruction readings (VOR) has traditionally been used to determine vegetative structure for wildlife (Robel et al. 1970, Uresk et al. 1999, Geaumont 2009), it also has the potential to provide an alternative method for estimating standing crop on rangelands (Benkobi et al. 2000, Ganguli et al. 2000, Vermeire and Gillen 2001, Woehl 2010). Visual obstruction readings (VOR) do have limitations, providing no output for indicators of biologic integrity or ecological and hydrological functionality of the system (Gearhart 2011). Visual obstruction readings provide estimates of total standing crop irrespective of the age of the vegetation. This lack of distinguishing between previous and current years standing crop can hamper management decision, specifically when determining grazing pressure (Volesky et al. 1999).

Analyzing height to weight relationship between clipped data and VOR allows one to determine and evaluate the effectiveness of VOR at predicting standing crop. If determined to be reliable, VOR could provide land managers with a quick and easily implemented method to predict standing crop. To this end VOR is being used by the United States Department of Agriculture's United States Forest Service (USFS) to determine standing crop following the grazing season on the DPG (Benkobi et al. 2000). Our study took place on three common ecological sites; loamy, thin loamy, and claypan at two locations within the DPG, the Little Missouri National Grasslands (LMNG) and Grand River National Grasslands (GRNG). The study objective was to determine the biological capabilities of each ecological site to obtain high structure as defined by the USFS (Table 1), and evaluate the relationship between VOR and clipped standing crop for each ecological site.

Table 1. United States Department of Agriculture Forest Service plan for recommended structure on pastures in the Little Missouri National Grasslands and Grand River National Grasslands (Svingen 2009).

Percentage of Landscape	**Visual Obstruction Reading**
10 - 20% Low	0 -1.5 inches
50 - 70% moderate	1.5 - 3.5 inches
20 - 30% high	> 3.5 inches

LITERATURE REVIEW

Methods For Estimating Standing Crop

Accurate measurements and monitoring of aboveground biomass (phytomass) is an essential element to calculate forage availability and stocking rate (Harmoney et al. 1997). Hand clipping by species, drying, and weighing vegetation provides the most accurate estimates of phytomass and species density; however, it is a time and labor intensive technique, requiring significant training, and numerous samples to obtain reliable estimates. Several double sampling techniques have been developed as alternatives to clipping. These methods function by visually estimating herbage weight for a large number of plots using predictive variables such as plant height, leaf area, vegetation density, age, and cover (Pechanec and Pickford 1937; Cochran 1977). A percentage of the plots are visually estimated and clipped, with the vegetation from clipped plots dried and used to correct visual estimates through a regression model. Pechanec and Pickford (1937) suggest a double sampling method termed the weight-estimate method, where estimates are made on plots located in a gridiron or patterned arrangement. The weight-estimate method showed a strong relationship ($R^2 = 0.9197$) between estimates and actual weights on individual plots. Similar to clipping by species, double sampling techniques can be expensive and time consuming; however, once a relationship has been established clipping is only necessary for calibration. In order to reduce time and labor spent clipping, t-Mannetje and Haydock (1963) developed the dry-weight rank method. This method uses a quadrat and allows an observer to estimate the amount of phytomass for each species within the quadrat. The dry-weight rank method requires several days of training and has shown a significant amount of variability among observers (Friedel et al. 1988).

The most accurate method for determining phytomass on rangelands is by cutting and weighing phytomass (Harmoney et al. 1997). Faster methods require less time and labor, allowing land managers and producers to spend less time and money monitoring, and to monitor more regularly. Numerous fast non-destructive instruments and techniques have been developed to provide estimates of standing crop (SC). The canopy analyzer (CA) indirectly estimates leaf area index (LAI), allowing fast nondestructive estimates of SC (Welles and Norman 1991). Research investigating the relationship between CA and SC has generated varying results, and in most instances the CA proved to be a poor predictor of SC (Harmoney et al. 1997; Miller-Goodman et al. 1999). Canopy height (CH) is done quickly and non-destructively, using measuring sticks (Harmoney et al. 1997), plastic disks (Sharrow 1984), and plates (Whitney 1974). Canopy height produced relatively poor estimates of SC on native short-grass plains (Ganguli et al. 2000). The weighted plate measurement (WP) allows for rapid repeatable measurements and has shown a strong relationship in its ability to estimate SC (Murphy et al. 1995; Ganguli et al. 2000). In contrast, Fehmi and Stevens (2009) found WP as a poor predictor of SC, explaining only half or less of the variability in herbage production. In a comparison of four non-destructive methods, Ganguli et al. (2000) found the Robel pole to be the most appropriate for estimating SC in the short-grass plains, with the WP producing good correlations. Similarly, Harmoney et al. (1997) found a modified Robel pole to be the most accurate estimator on grass observations when taking measurements on a variety of species. In contrast, Limb et al. (2007) reported their digital image method used to estimate SC showed less variation among observers (6.8%), and was lower ($P<0.05$) than both the Nudd's coverboard (32.1%) and Robel pole (52.2%). The digital image method also provide better estimates of SC ($R^2 = 0.89$) compared to the Robel pole ($R^2 = 0.68$), accounting for 21% more of the observed variation in biomass.

Visual Obstruction Reading

Visual obstruction reading is a type of monitoring protocol used by the Dakota Prairie Grasslands to determine height and density of standing herbage (structure) as a function of residual cover in an allotment or pasture at or near the end of the grazing season. The Robel pole has become the more favored method in determining standing structure as an assessment for sharp-tailed grouse nesting habitat. The use of a Robel pole was originally designed to evaluate the habitat potential of grasslands for prairie chickens by providing an estimate of SC (Robel et al. 1970). The SC on rangelands is a valuable asset for livestock production, wildlife food and cover, as well as soil protection against erosion (Benkobi et al. 2000). The USFS uses the Robel pole to determine if management is meeting the desired herbaceous structure distribution across the landscape (USDA, Forest Service 2006a). This method is currently conducted on the USFS Dakota Prairie Grasslands, LMNG, GRNG and Sheyenne National Grasslands (USDA, Forest Service 2006a).

The Robel pole has received substantial attention in the literature the past 40 years (Robel et al. 1970; Volesky et al. 1999; Benkobi et al 2000; Vader 2000; Vermeire and Gillen 2001; Uresk and Benzon 2007; Uresk et al. 2010; Woehl 2010; Uresk 2012). The VOR is determined by observing a graduated pole at a specified height and distance from the pole. While VOR had been suggested for use in estimating standing herbage prior to the 1970's (Webb 1942; Wight 1938), Robel et al. (1970) was the first to develop the graduated pole that is used by scientist and land management agencies. Robel et al. (1970) suggested a 3 cm x 150 cm pole with white and light brown alternating decimeter stripes. Benkobi et al. (2000) modified the pole to alternating white and grey stripes, 2.54 cm (1 in) thick with each stripe numbered. Further modification was done by Vermeire et al. (2002) to a pole with alternating red and white decimeter bands with black lines marking every 2 cm. The modified Robel pole with 2.54 cm bands offers an improved method for monitoring standing herbage and structure of grasslands (Benkobi et al. 2000). Uresk and Juntti (2008) suggest when monitoring heavily grazed areas or short vegetation such as that occurring at high altitudes or xeric sites, 2.54 cm VOR bands are insufficiently precise; creating the need for a pole with 1.27 cm bands. Following the development of a relationship between VOR and SC (live and dead), the modified Robel pole provides the potential for quick, simple, and accurate estimates of SC (Uresk 2012).

Height: Weight Correlation

While the use of VOR is standard practice by wildlife biologist for determining structure on grassland habitat, it has not been widely adopted for estimating SC by those interested in plant productivity (Jackson and Paine 2006). Recently, VOR has gained interest from the USFS for its potential to estimate herbage production from structure (Benkobi et al. 2000; Limb et al. 2007). Robel et al. (1970) was one of the first to correlate vegetation present at a site with indices to the VOR. In order to quantify the VOR technique for evaluating height and density, comparisons were made between VOR and weight of clipped vegetation on sample plots. The VOR were taken at heights of 1.0, 0.8, and 0.5 m and at distances of 4, 3, and 2 m. Following the collection of VOR, vegetation was clipped to a height of 5 cm using a 20 X 50 cm rectangular frame. A multiple linear regression analysis was used to measure the relationship between VOR and the weight of clipped vegetation from each transect. At each measurement a strong relationship was found between VOR and weight of the vegetation clipped from each transect. The most significant relationship was found between the mean of all VOR and weight of vegetation clipped from each transect ($P<0.01$), with high correlation coefficient ($R=0.9727$) detected. The VOR taken from a distance of 4 m and a height of 1 m provided a very reliable measure of height and density of the vegetation, contributing (0.9550) to the overall R^2 (*0.9727*). These results led to the standard protocol for VOR with measurements taken at a distance of 4 m and a height of 1 m.

Benkobi et al. (2000) found VOR to be an excellent predictor of SC on sandy lowland range sites in the Nebraska Sandhills (r^2 =0.88). Uresk (2012) also reported strong correlations for selected ecological sites on the Fort Pierre National Grasslands in South Dakota. Uresk (2012) reported a coefficient of determination of 0.79 on the shallow clay and loamy ecological sites, and 0.82 on the clayey ecological sites. Jackson and Paine (2006) studied grass stands with single species seeding that were rotationally grazed by bison in southern Wisconsin, reporting a VOR correlation of r^2 =0.76 for SC when readings were grouped at the transect level. In contrast, when observations were compared at the individual sample level or grouped by experimental species plots, a weak relationship was observed (r^2 = 0.14 and 0.17, respectively).The scale at which VOR are paired for analysis may have a significant effect on the relationship between VOR and clipped phytomass production (Jackson and Paine 2006). In a review of four studies that used transects or pasture as the experimental unit to generate a regression equation, the average r^2 was 0.79 (Ackerman et al. 1999; Benkobi et al. 2000; Vermeire et al. 2002; Jackson and Paine 2006). In contrast, two studies that used individual sample locations when developing the regression equation generated an r^2 value of 0.39 (Harmoney et al. 1997; Jackson and Paine 2006).

Jackson and Paine (2006) found that when averaging transects within sown species, only sideoats grama (*Bouteloua curtipendula*) had a significant improvement in its relationship between VOR and clippings (r^2 = 0.54 as opposed to r^2 = 0.17 for all other sown species treatments). In comparing sideoats grama plots and other species, the main difference was sideoats grama had the lowest median VOR (2.89 cm), while all other species treatments had median VOR above (3.0 cm). The sideoats grama treatments also had the greatest presence of annual grasses at 13.2%, with all other treatments < 10%. The annual grasses may have created a more homogeneous stand, where the biomass would not carry over from year to year.

The overall vegetation height may affect the ability of researchers to obtain strong relationships between VOR and clipped phytomass (Jackson and Paine 2006). On grazed tallgrass prairie near Stillwater Oklahoma, Vermeire and Gillen (2001) observed a regression (r^2) of 0.64 on non-burned, grazed pastures at the subsample level. In contrast, on sites that had not been grazed since 1982 on the shortgrass plains in Texas, Ganguli et al. (2000) reported regression models of $r^2 = 0.87$ at the transect level and 0.85 at the subsample level. These results could be due to the overall greater potential height of a tallgrass prairie or as a result of grazing creating a more heterogeneous vegetation structure. Both would likely create more variability for VOR and clipping, creating increased difficulty in order to obtain a strong regression relationship. However, Vermeire and Gillen (2001) did report an r^2 of 0.79 on burned sites near Stillwater, which may have been due to an increase in homogeneity on those sites.

While studying shortgrass plains and mixed prairie, Vermeire et al. (2002) reported an r^2 of 0.91 and 0.89; respectively, at their study site in Texas. The shortgrass plains study site was described as having 80% blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloe dactyloides*), while the mixed prairie was dominated by blue grama, purple threeawn (*Aristida purpurea*), silver bluestem (*Bothriochloa lagurides*), and buffalograss. Vegetation on the mixed prairie had not been grazed by large herbivores since 1982, likely increasing structural homogeneity. The strong relationship reported between VOR and clippings on these sites provides support to the idea that a relationship exists between high r^2 and increased structural homogeneity (Jackson and Paine 2006). Damiran et al. (2007) found relatively poor correlation on northwestern bunchgrass prairie rangelands ($r^2 = 0.46$). The lack of a strong correlation may be partially explained by the heterogenic structure that is described throughout the study site. However, Uresk and Juntti (2008) reported an r^2 value of 0.81 on a study conducted on the Bighorn National Forest, suggesting that VOR has the potential for success outside of grassland ecosystems.

A comparison of Robel pole models based on regression slopes (kg ha^{-1} *band [2.54cm]) using the model developed by Benkobi et al. (2000) shows differences in regression slopes between different vegetation types and regions based on other studies (Uresk 2012). The regression slope for clayey ecological sites on the Fort Pierre National Grasslands Uresk (2012) was 15% lower than what Benkobi et al. (2000) found on sandy ecological sites in the Sandhills of Nebraska, with the combined shallow clay and loamy overflow ecological sites at a 10% lower slope (Uresk 2012). In Kansas, Robel et al. (1970) had a 53% lower regression slope than Benkobi et al. (2000) reported in Nebraska. In the Black Hills of South Dakota (Uresk and Benzon 2007) and Big Horn Mountains of Wyoming (Uresk et al. 2010), researchers showed a 76% and 45% lower regression slopes respectively as opposed to Benkobi et al. (2000). The wide ranges observed in regression slopes emphasize the idea that no one model fits across regions and ecological sites, creating the need for new regression models for each ecological site and region (Uresk 2012).

In general, VOR has been a good predictor of herbaceous SC (Robel et al. 1970; Benkobi et al 2000; Ganguli et al. 2000; Vermeire et al. 2002; Uresk and Benzon 2007; Uresk and Junti 2008). However, some research has failed to produce strong relationships (Volesky et al. 1999; Woehl 2010). The differences observed among studies may be attributed to sampling procedures (Vermeire et al. 2002). The area that is measured by VOR is believed to be truly three dimensional and variable among points (Vermeire and Gillen 2001). Frames that measure only the vegetation affecting the VOR and use means of VOR readings and clipped estimates as observations may have the potential to reduce some of the variation in model development (Vermeire et al. 2002).

While the body of literature suggests that the Robel pole should perform well when used in reasonably uniform vegetation, the mosaic landscape that grassland vegetation represents makes accurate estimation of SC at a given time a difficult task for land managers and scientist (Jackson and Paine 2006). The disadvantage of VOR is that it provides no data for indicators of biologic integrity or ecological and hydrological functionality of the system (Gearhart 2011). Additionally, VOR along with other indirect sampling methods only provide estimates of total vegetation weight, while it is often necessary to distinguish between previous and current years herbage when determining grazing pressure (Volesky et al. 1999). Species diversity is also not addressed by indirect sampling methods such as VOR.

Livestock Production and Wildlife

Livestock production and wildlife habitat objectives become antagonistic on grasslands when the need for standing herbage for key wildlife species limits the amount of forage that can be removed by livestock (Reece et al. 2001). A dynamic relationship exists between livestock and rangeland wildlife habitat. Herbage on rangelands provides much of the primary nutrients for livestock and is often the only source of nesting cover for many grassland bird species. Standing herbage following grazing and the growing season provide the only source of cover for birds seeking nesting sites early the following spring. The quality of nesting cover on grasslands has been shown to decline as stocking rates increase (Duebbert et al. 1986). Implementation of grazing management strategies that provide adequate cover for successful nest sites in the early spring has shown to increase mean clutch size of many grassland bird species (Kantrud and Higgins 1992; Fredrickson 1996). This strategy also allows chicks to develop before the summer heat stress becomes a threat to survival.

Cumulative grazing pressure, timing of grazing, moisture, along with plant species and distribution of plants species are important factors in understanding the effects of grazing management decisions on wildlife cover (Schroeder and Braun 1992). Hamerstrom et al. (1957) found that height and density of grass were of greater importance to prairie chicken nesting cover than species composition. Hamerstrom et al. (1957) findings were a major driving factor in the development of a measuring tool to evaluate the height and density of vegetation (Robel et al. 1970). Since its development, much of the research conducted with the Robel pole has assessed different management techniques on wildlife habitat and upland nesting birds (Higgins 1977; Kobriger 1981; Sedivec 1994; Messmer 1985; Hertel 1987; Grosz 1988; Sedivec 1989; Uresk et al. 1999; Uresk and Benzon 2007; Uresk and Juntti 2008; Geaumont 2009). While studying pheasant and duck nesting cover on post Conservation Reserve Program land in western North Dakota, Geaumont (2009) found when 50% or more of the land had cover of greater than 25 cm, 57% of nests were successful. Higgins (1986) used the Robel pole to measure preferences of different shrub communities by various bird species and showed areas with higher vegetative structure had higher bird density and increased bird species diversity.

Sharp-tailed Grouse

The VOR method for inventorying SC developed by Robel et al. (1970) and Benkobi et al. (2000) was used to create a habitat suitability index based on vegetation visual obstruction, ranging from 0-77.5 cm (0-30.5 inches) with a suitability index rating of 0-1.0 (Prose 1987). Studies of nesting habitat by Prose et al. (2002) in the Nebraska Sandhills found that nesting sharp-tailed grouse selected nest sites with a VOR of more than 4 cm (1.57 inches). Similarly, Reece et al. (2001) observed that sites with a VOR of less than 5 cm (1.97 inches) near potential nesting locations indicated a decline in quality nesting habitat as average VOR declined.

The use of the Robel pole to assess habitat for sharp-tailed grouse has given managers a target height for vegetative structure to obtain near the end of the grazing season. This target height allows managers to assess current conditions with desired vegetation height when determining management strategies. The USFS classifies a mean VOR of 8.89 cm (3.5 in) from a 200 m transect as high structure and desirable habitat for sharp-tailed grouse nesting hens (USDA, Forest Service 2001). The 8.89 cm standard for high structure only needs to be achieved on sites defined as biologically capable. The USFS definition for biologically capable is any site classified as one of the following habitat types: western wheatgrass (*Pascopyrum smithii*)/green needlegrass (*Nassella viridula*), western wheatgrass/needle-and-thread grass (*Hesperostipa comata*), needle-and-thread/sedge (*Carex* spp.), silver sage (*Artemisia cana*) /western wheatgrass, big sagebrush (*Artemisia tridentata*)/western wheatgrass, or western snowberry (*Symphoricarpos occidentalis*). Sites dominated by crested wheatgrass were also considered biologically capable. These habitat types, as well as crested wheatgrass sites, are generally capable of producing 1232 kg/ha of herbaceous material, and most are capable of producing 1568 kg/ha or more (USDA, Forest Service 2006b).

General habitat requirements for sharp-tailed grouse are characterized by low, sparse vegetation for lek sites and brushy or woody vegetation with patches of tall dense grass being key components for nest cover and early brood rearing stages (Prose 1987; Houchen 2011). Habitat selection for nesting grouse is most often compelled by predator avoidance, with premium sites providing both overhead and lateral cover to conceal nests from both avian and mammalian predators (Bergerud and Gratson 1988). Nesting sites for sharp-tailed grouse are usually located under or near shrubs and have taller and thicker residual vegetation (Prose et al. 2002). Residual vegetation is a key aspect of the herbaceous understory, since it provides concealment of the nest during early incubation periods before new growth begins in the spring. The selection of shrub-dominated habitats by nesting females is believed to be due to changes in habitat conditions as native grassland communities have diminished (Goddard et al. 2009).

On the Grand River National Grasslands in northwest South Dakota, sharp-tailed grouse nest survival rate increased with an increase in maximum vegetation height and increasing canopy cover of grass (Houchen 2011). Similarly, Goddard et al. (2009) found that at the patch and site scales, sharp-tailed grouse nesting females selected shrub-steppe habitats, greater shrub and grass cover, taller vegetation, and greater residual vegetation compared to random sites. Hamerstom and Hamerstom (1961) suggest that the most effective management practice for maintaining suitable habitat for sharp-tailed grouse in rangelands is to apply moderate grazing pressure. In a comparison of landscape composition around active and inactive lek sites, Hanowski et al. (2000) determined that inactive sites had larger proportions of upland forest and brush cover types, while active sites had a greater percentage of native grass species. In Alberta, Canada, Berger and Baydack (1992) found leks deserted when the native grass/sedge species decreased below 15% of the area within a 1,000 m diameter surrounding the lek.

Environmental Impacts

Annual forage production on any given ecological site is largely dependent on environmental factors. Numerous studies in the Northern Great Plains have reported a positive relationship between precipitation and forage production (Smoliak 1986, Sala et al, 1988). Patton et al. (2007) reported that production was greater on grazed treatments than on un-grazed treatments when precipitation was greater than 248.4 mm from the end of the growing season in the previous year to the end of the grazing season in the current year on overflow ecological sites. Smoliak (1986) found that the strongest correlation between forage production and precipitation occurred when accounting for precipitation from the previous September plus current year April through July. While other environmental factors certainly play a role in forage production, a relationship is not often reported (Patton et al. 2007).

Grazing Pressure

Paine et al. (1996) conducted a study to determine the effects of livestock grazing on upland nesting birds. Three different stocking rates showed no difference in upland nesting bird survival, with 25% for all stocking rates. Reece et al. (2001) reported that VO in un-grazed control pastures declined by 11% from 12.3 cm in 1995 to 11.0 cm in 1996, and 15% to 9.3 cm from 1996 to 1997. These declines were attributed to lower cumulative precipitation during these years. In addition they found that grazing pressure accounted for about twice as much variation in fall cover among pastures after July grazing (R^2=0.62) compared to June grazing (R^2=0.34). This was attributed to rapid plant regrowth from mid-June to mid-July having the ability to offset the effects of high grazing pressure from June grazing. In June, VO declined by 1 cm for each 23 Animal Unity Days Mg^{-1} increase in cumulative grazing pressure. While July grazing showed a decline of 1 cm for each 9 AUD Mg^{-1} increase in cumulative grazing pressure up to 40 AUD Mg^{-1}. They concluded that the amount of standing herbage remaining on Sandhills pastures in July to be a critical factor in determining the quality of cover for wildlife after a killing frost.

STUDY AREA

The study was conducted on the Dakota Prairie National Grasslands (DPG) within the Little Missouri National Grassland (LMNG) of North Dakota and Grand River National Grassland (GRNG) of South Dakota (Figure 1). The GRNG is managed by the USDA Forest Service Grand River Ranger District (GRRD) and comprised of 62,726 ha. The LMNG is managed by the USDA Forest Service McKenzie Ranger District (McKRD) to the north and the Medora Ranger District (MRD) to the south and comprised of 404,685 ha.

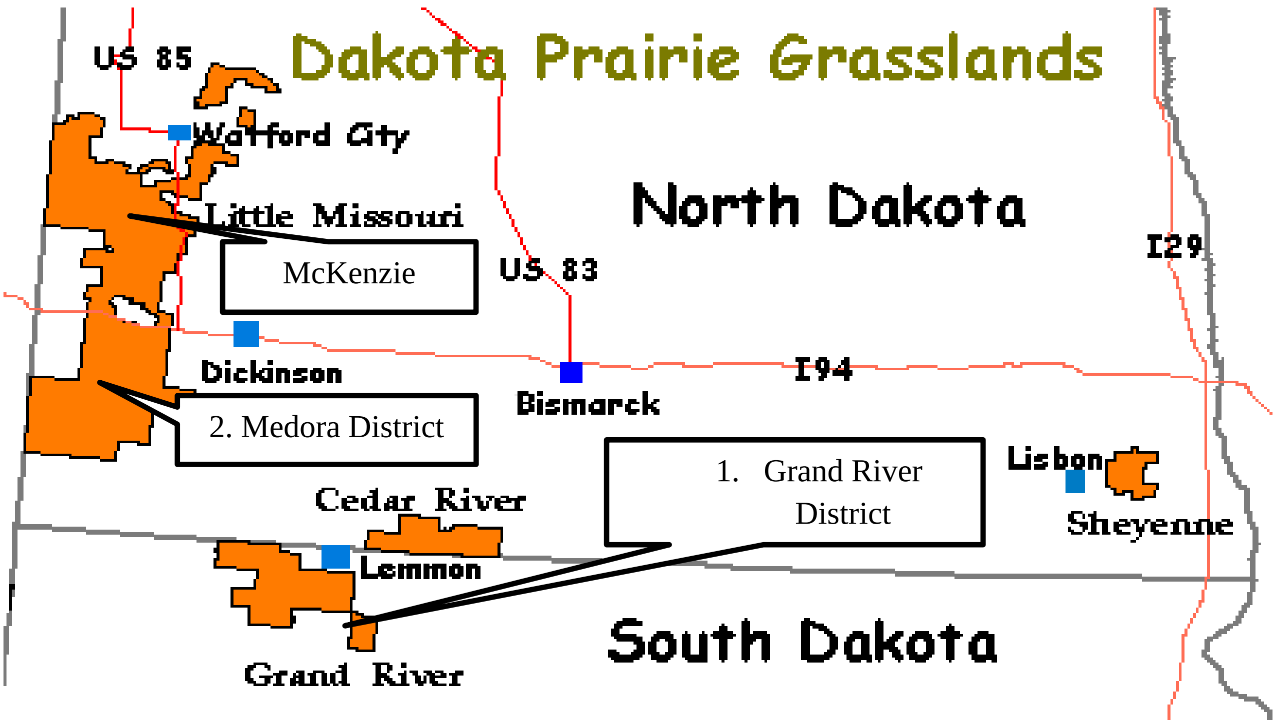

Figure 1. Location of the Grand River National Grasslands, Grand River Ranger District (1), Little Missouri National Grasslands McKenzie Ranger District (2) and Medora Ranger District (3) in North and South Dakota (USDA Forest Service 2014).

The GRRD is in Perkins County South Dakota, and located in the northwest region of the state. The area is located on an upland plain that is dissected by streams and drainage ways

(Wiesner 1980). Relief in the area ranges from gently rolling too steep, with a number of prominent buttes and ridges throughout the landscape. The soils are mainly moderately deep to shallow, loamy, and nearly level to steep. The elevation ranges from 708 to 888 m above sea level (USDA, Forest Service 2001).

The McKRD is located in McKenzie County found in the northwestern portion of North Dakota. The soils of the McKRD developed from yellow and ash-gray shales, sandstones, and clays of the Fort Union formation (Hanson and Whitman 1938). The area is also made up of numerous beds of lignite, baked shale and sandstone called “scoria” (Gauger et al. 1930). Due to erosion by wind, water, and burning lignite veins the area has a large amount of heterogeneity in the topography as plateau tops, slopes, terraces, valleys, buttes, low hills, and knobs of numerous shapes (Hanson and Whitman 1938). Elevation ranges from 549 to 1,067 m above sea level (USDA, Forest Service 2001).

The study areas were located within Major Land Resource Area (MLRA) 54, which is located in the Missouri Plateau, unglaciated and glaciated sections of the Great Plains (USDA, Natural Resource Conservation Service 2006). The unglaciated portion of MLRA 54 is dominant, with only the eastern and northern edges glaciated. The parent material consists of soft, calcareous shales, siltstones and sandstones. The most prominent soil orders are Mollisols and Entisols dominated by a frigid soil temperature regime, an ustic soil moisture regime, and smectitic (mixed) mineralogy.

The vegetation in the LMNG and GRNG is dominated by mixed grass prairie, intermixed with short grass prairie. Common plants found in the area include western wheatgrass *(Pascopyrum smithii (Rydb.) A. Love)*, green needlegrass *(Nassella viridula* (Trin.) Barkworth), blue grama *(Bouteloua gracilis* (Willd. Ex Kunth) Lag. Ex Griffiths), needle-and-thread *(Hesperostipa comata* (Trin. & Rupr.) Barkworth), little bluestem *(Schizachyrium scoparium* (Michx.) Nash), prairie sandreed *(Calamovilfa longifolia* (Hook.) Scribn.), sideoats grama *(Bouteloua curtipendula* (Michx.) Torr.), prairie junegrass *(Koeleria macrantha* (Ledeb.) Schult.), threadleaf sedge *(Carex filifolia* Nutt.), prairie rose *(Rosa arkansana* Porter), leadplant *(Amorpha canescens* Pursh), green ash *(Fraxinus pennsylvanica* Marshall), American elm *(Ulmus americana* L.), boxelder *(Acer negundo* (L.) Var. negundo), silver sagebrush *(Artemisia cana* Pursh), buffaloberry *(Shepherdia argentea* (Pursh) Nutt.), snowberry (*Symphoricarpos occidentalis* Hook.), and chokecherry *(Prunus virginiana* L.) (USDA, Forest Service 2001).

Several introduced grass species, such as crested wheatgrass *Agropyron cristatum* (L.) Gaertn), Kentucky bluegrass *(Poa pratensis* L.), and smooth brome *(Bromus inermis* Leyss.), comprise the landscape. The prominent wildlife species are white-tailed deer *(Odocoilenaus virginianus)*, mule deer *(Odocoileus hemionus)*, pronghorn antelope *(Antilocapra americana)*, red fox *(Vulpes vulpes)*, coyote *(Canis latrans)*, white-tailed jackrabbit *(Lepus townsendii)*, prairie dog *(Cynomys ludovicianus)*, ring-necked pheasant *(Phasianus colchicus)*, gray partridge (*Perdix perdix)*, sharp-tailed grouse (*Tympanuchus phasianellus)*, ducks, and geese (*Branta canadensis)*, (USDA, Natural Resource Conservation Service 2006). The vast majority of the area comprises farms and ranches, which produce a combination of cash-grain crops, hay and livestock. A little more than half of the area supports native plant species that are grazed by livestock, while nearly one third of the area used to produce cash crops and forage hay. Soil and wind erosion are the biggest concerns in terms of soil conservation.

Climate

The climate for MLRA 54 is considered semi-arid Continental, with warm summers and cold winters (USDA, Forest Service 2001). The mean precipitation for the area ranges from 355 to 455 mm, mostly occurring during the growing season (USDA, Natural Resource Conservation Service 2006). The mean annual temperature is 3 to 7 degrees C. Growth of native cool-season plants begins late March and continues through early to middle July (USDA, Natural Resource Conservation Service 2010). Native warm-season plants begin growth later, usually mid-May, and will continue growth near the end of August through mid-September. In years that receive fall moisture, a green up period often takes place for the cool season plants in September and October. The area has a frost-free period ranging from 119 to 136 days.

Ecological Sites

Ecological site classifications are designed to aid in land management. An ecological site is a specific site on rangeland that historically produces a characteristic natural plant community that is different than the natural plant community of other ecological sites in kind, amount, and proportion of range plants (Aziz et al. 2006, Sedivec and Printz 2012). Each ecological site was developed under the consideration of climate, biota, topography, available soil moisture, soil texture, soil chemistry, and soil depth (Sebesta 2010). Climate dictates the temperature and amount of precipitation in a given area. Topography plays a role in available soil moisture by influencing the rate of runoff and infiltration. Soil depth may also be impacted by topography due to its influences on erosion. Plant growth is reliant on precipitation, temperature, available soil moisture, soil texture, soil depth, and available nutrients. Micro and Macro fauna, critical in soil formation and nutrient cycling, also rely on these same factors.

The relationship between vegetation and soils is a complex dynamic (Hanson and Whitman 1938). The development of soil is strongly influenced by the native vegetation, just as the soil is instrumental in the development and structure of native vegetation. The soil and vegetation both develop under the control of environmental forces acting upon them. Kearney et al. (1914) studied the distribution of vegetation in relationship to the physical and chemical properties of soil and found a strong relationship between moisture content, soil texture, alkali salts, and vegetation. Similarly, a strong relationship has been shown to exist between vegetation type and topographical position (Hanson and Whitman 1938). The influence that topographical position plays on vegetation type is due to the different environmental factors that are present at different topographical positions. This is not a recent phenomenon as soil surveyors have frequently used landscape position to describe soil series and differences in soil characteristics. Significant information can be gathered on soil moisture conditions and geological material based on topographical position.

Ecological sites are used to classify soils that produce similar kinds, proportions, and amounts of vegetation in areas that have similar climate and topography (Aziz et al. 2006, Sedivec and Printz 2012). When precipitation and other climatic forces are similar, an increase in available moisture in the soil is apparent based on the difference in vegetation (Hanson and Whitman 1938). The presence of a water table or seepage from another area is the two main sources for any increase in available water. Over time and with limited disturbance, the combination of plants best suited to a particular climate and soil are established (Aziz et al. 2006). This group of plants is known as the natural plant community or climax plant community for the given site. Typically the climax plant community will be the most productive and diverse combination of plants that can occur on a site. The ecological site description helps one interpret the ecological and utilitarian values of a specific site including grazing, wildlife habitat, watershed protection, recreation, and other uses.

Claypan Ecological Sites

Claypan ecological sites occur on gently undulating to rolling sedimentary uplands in MLRA 54 (USDA, Natural Resource Conservation Service 2010). Common soil series for claypan sites in MLRA 54 include Daglum, Janesburg, and Parchin. These soils are formed in soft siltstone, shales, and alluvium and are moderately well to well drained. The surface layer ranges from 10 to 38 cm thick with a fine sandy loam to clay loam texture with slopes of 0 to 15 percent. The subsoil is characterized by an extremely hard clayey Btn horizon with columnar structure and high levels of sodium. The infiltration rate is moderate to slow with very slow hydraulic conductivity. Claypan ecological sites are often susceptible to water erosion if sufficient vegetative cover is not maintained. The reference plant community for claypan sites is western wheatgrass/blue grama/needlegrasses. When these sites have extended periods of non-use and lack of fire they become susceptible to exotic invasive species such as Kentucky bluegrass and smooth bromegrass. Annual production on claypan ecological sites ranges from 1121 to 2242 kg/ha (Sedivec and Printz 2012).

Loamy Ecological Sites

Loamy ecological sites occur on gently undulating to rolling sedimentary uplands in MLRA 54 (USDA, Natural Resource Conservation Service 2012). Common soil series for loamy ecological sites in MLRA 54 include Amor, Reeder, and Vebar. These soils are well drained and formed in soft siltstone, sandstone or alluvium. These sites will have soils that have a silt loam to clay loam textured subsoils with slopes of 2 to 20 percent. The surface layer is 12 to 30 cm thick with a loam to silt loam texture. The infiltration rate is moderate. Loamy sites may have some presence of water flow patterns and may be susceptible to rills and gullies if insufficient vegetation is not present. This site is vulnerable to the invasion of Kentucky bluegrass and smooth bromegrass and may increase in shrub communities such as western snowberry when mis-managed. The reference plant community is western wheatgrass/green needlegrass with production ranging from 1569 kg/ha to 3811 kg/ha (Sedivec and Printz 2012).

Thin Loamy Ecological Sites

Thin loamy ecological sites occur on moderately steep to steep sedimentary uplands in MLRA 54 (USDA, Natural Resource Conservation Service 2012). Soil series comprising thin loamy ecological sites include Cherry, Lantry, and Maschetah. Common soil features of thin loamy ecological sites are the strong presence of calcareous silt loam to calcareous fine sandy loam subsoils. The sites are typically found on shoulders and backslopes with slopes of 6 to 35 percent. The soils are well drained and were formed from soft siltstone, loess, or glacial till deposits. These soils are highly susceptible to water and wind erosion when the proper vegetation is not maintained. The reference plant community is needlegrass/bluestem/western wheatgrass. Under continuous grazing without adequate rest periods, this site has the potential to depart from the reference plant community with species such as western wheatgrass and blue grama initially increasing while little bluestem composition remains similar or reduced. Although a stable plant community, production is less under this changed community than that of the reference plant community. Runoff will also increase under this plant community due to decreased infiltration. Thin loamy sites are susceptible to excessive accumulation of litter when lightly to no grazing occurs, favoring exotic species such as Kentucky bluegrass, crested wheatgrass, and smooth bromegrass. In the reference plant community production on this site will range from 1121 to 2690 kg/ha (Sedivec and Printz 2012).

METHODS AND DESIGN

Three common ecological sites within the Grand River National Grasslands (GRNG) and Little Missouri National Grasslands (LMNG) (loamy, claypan, thin loamy) were selected to determine if they were biologically capable of producing 8.89 cm (3.5 in.) of vegetative structure. Plots were selected using the criteria and methods established by Natural Resource Conservation Service (NRCS) for classifying ecological sites. Plots were then verified by NRCS staff to confirm correct ecological site. Eight plots were selected for each ecological site at both study locations. The plots were selected to represent the vegetative phases closest to historic climax plant community (HCPC; first and second states and phases) based on availability in the state-and transition-model for each specified ecological site loamy (Figure 2), claypan (Figure 3) and thin loamy (Figure 4), on the GRNG and LMNG [3 ecological sites x 8 plots (replicates) x 2 locations = 48 plots] (USDA, Natural Resource Conservation Service 2012). Each plot was fenced in a 60 x 60 m^2 using electrical fence in spring of 2012 prior to cattle being turned out to exclude grazing during the study period and eliminate the livestock grazing variable. A 200 m transect was laid out in a 50 x 50 m^2 design so that the entire transect remained within the fenced exclosure. Transects followed the written USFS protocol and Robel pole measurements were collected every 10 m.

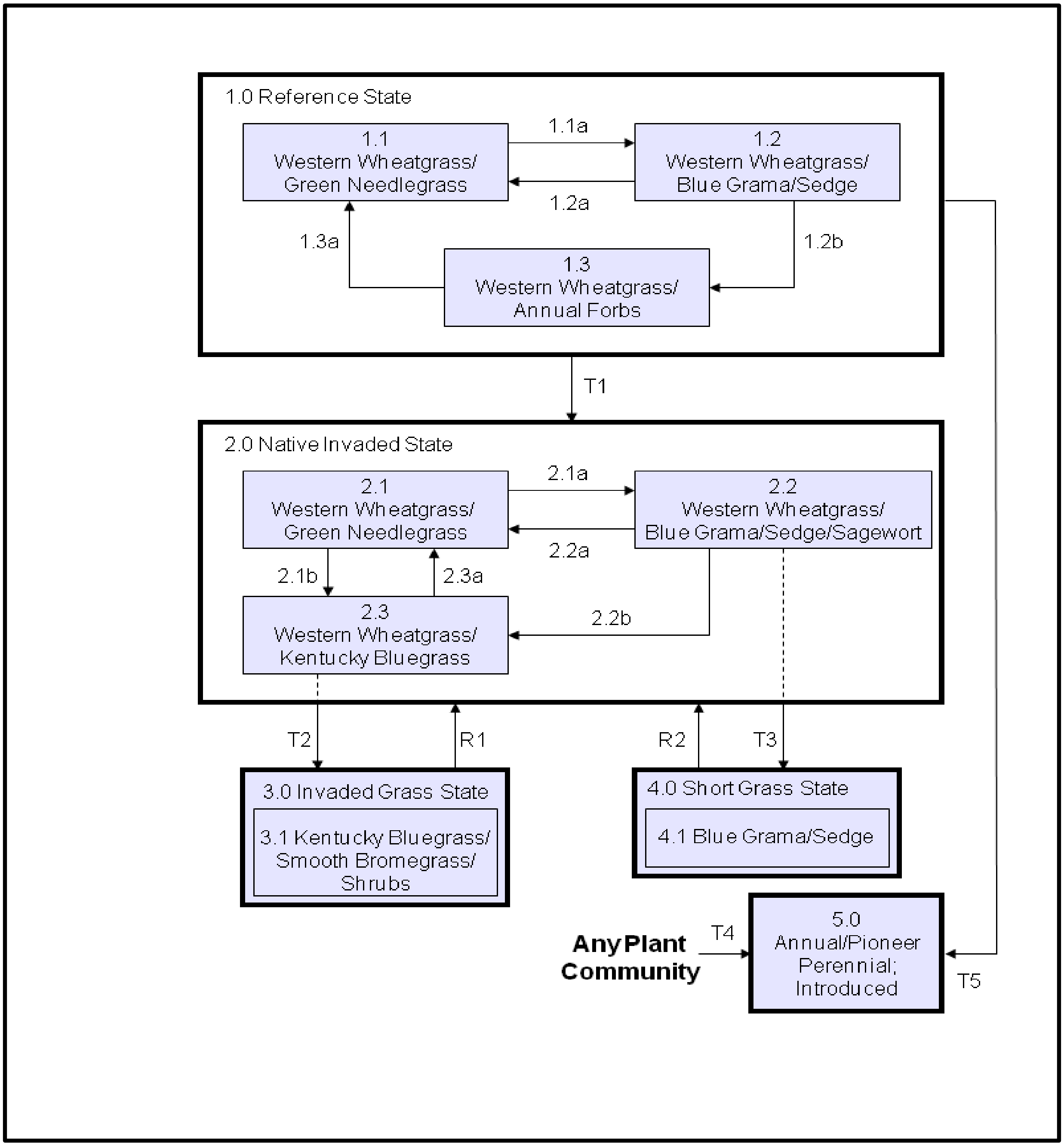

Figure 2. State and transition diagram for loamy ecological sites in major land resource area 54 (USDA, Natural Resource Conservation Service 2012).

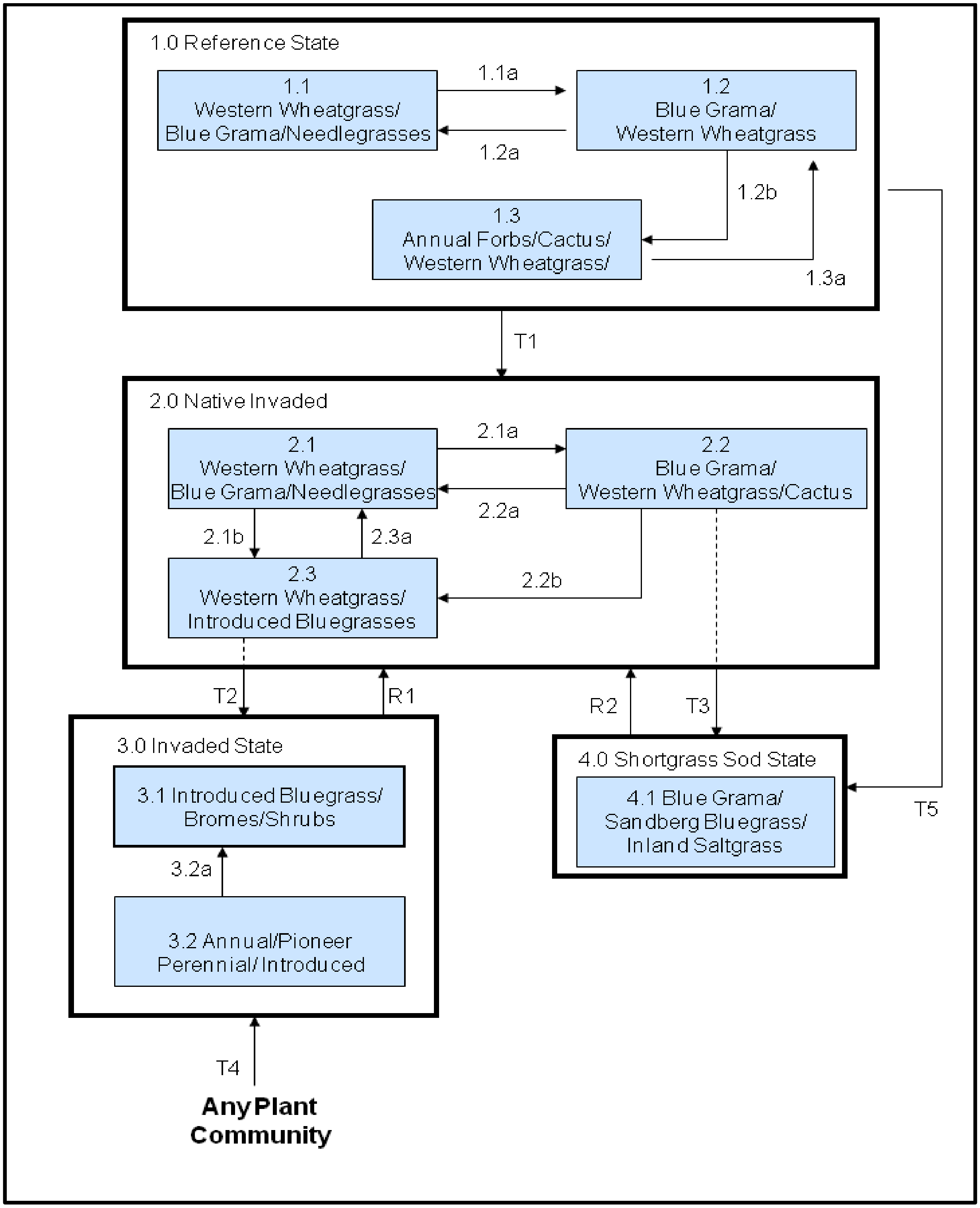

Figure 3. State and transition diagram for claypan ecological sites in major land resource area 54 (USDA, Natural Resource Conservation Service 2012).

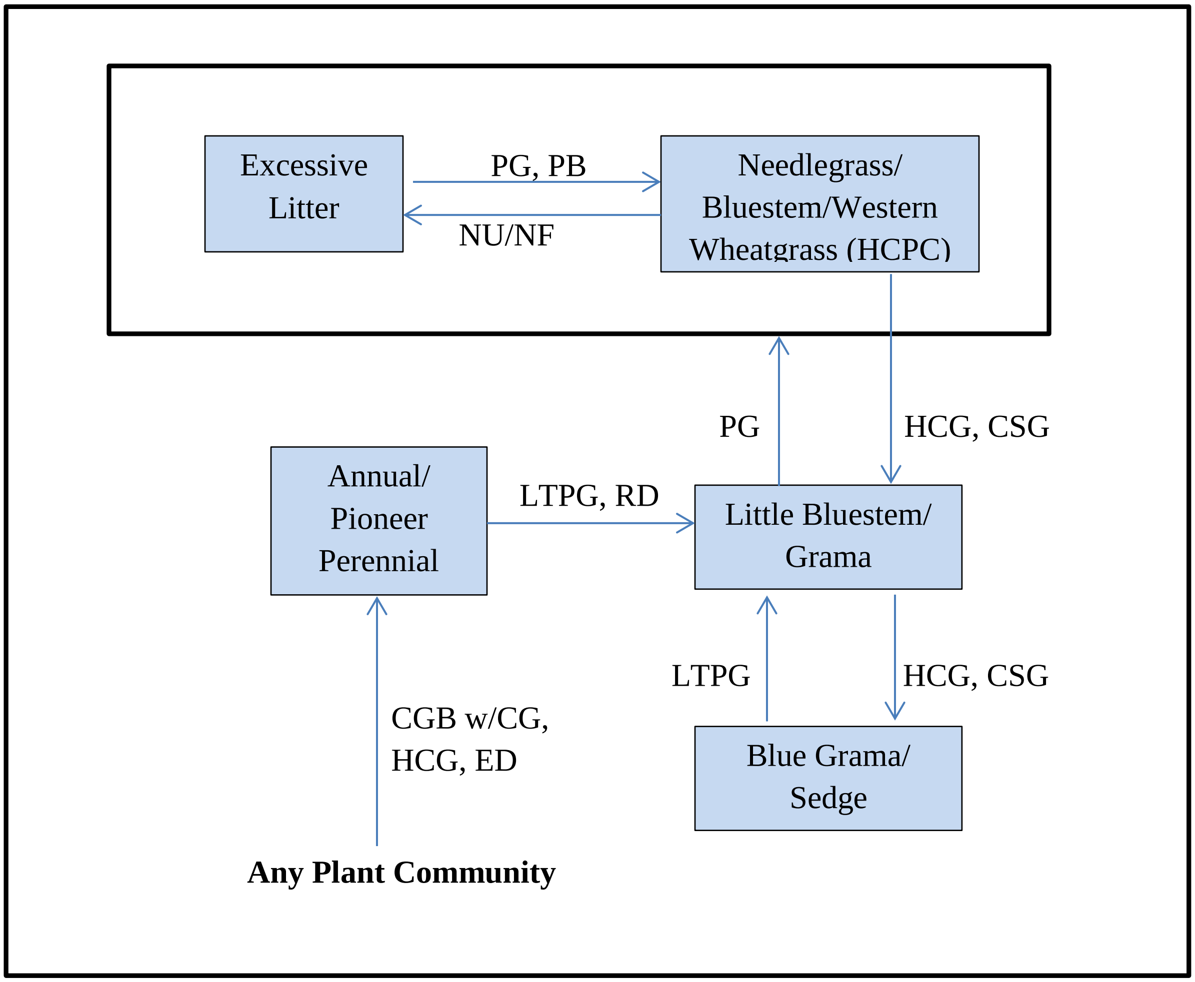

Figure 4. State and transition diagram for thin loamy ecological sites in major land resource area 54 (USDA, Natural Resource Conservation Service 2012).

Vegetative structure was determined using a modified Robel pole from Robel et al. (1970) and classified as VOR. The modifications included changing bandwidth to 2.54 cm as opposed to 1 decimeter described by Robel et al. (1970) and reading the last visible band with 2.54 cm (one in) being the lowest possible reading. Standing residual vegetation was collected by clipping to ground level using a 0.178m^2 hoop. Plots were clipped off center from VOR to avoid destruction of vegetation for future collection periods. Standing residual vegetation was collected during peak production (mid to late July) and near the end of the grazing season when the USFS traditionally reads VOR for structure (early to mid-October). The VOR were collected during these two periods as well as early spring prior to green-up and livestock turn out (between mid-April and early May). The VOR and clipped vegetation plots were collected in April, July and October, 2012.

The VOR was collected at 20 individual points every ten m along the 200 m transect with reading taken at each point from a distance of four m and a height of one m in all four cardinal directions (Benkobi et al. 2000). The four readings were then averaged to determine mean height of standing crop for each point. The mean from each point was then used to generate a mean for each plot and then each ecological site. Benkobi et al. (2000) suggests a minimum of 4 clippings for the dependant variable. Ten individual points were clipped to ground level using the 0.178 m^2 hoop every 20 m along the 200 m transect to determine weight of standing crop. Ten points were clipped as opposed to the minimum requirement of four in order to improve relationship between VOR and SC. Five of the ten points were clipped and sorted into litter, standing dead, and individual species while five were clipped and sorted by litter, standing dead, and phytomass. Clipped vegetation was dried at 55^{o}C for 72 hours to obtain total dry matter form clipped vegetation. Dried weights were recorded for each ecological site to determine standing crop and phytomass production.

The VOR was analyzed by generating a mean for each ecological site for each study area to determine if the site was biologically capable of producing 8.89 cm of structure during each of the three collection periods. Change in mean VOR and mean standing crop between fall to spring, and summer to fall collection periods was analyzed using a two tailed t test. Standard errors were determined for mean VOR and mean standing crop. Mean VOR heights and mean standing crop weights were used in a linear regression model where weight was the dependent variable “y” and VOR the independent variable “x”. A simple linear regression model was developed for the loamy, claypan, and thin loamy ecological sites to determine a height: weight relationship. Equation models were generated for each ecological site by study location when regressions were significant ($P \leq 0.05$). Standard errors of the predicted weights were determined for linear correlations at 95% confidence level and prediction limit.

RESULTS

Climate

Precipitation in the LMNG was 132% of the long term average for 2011, but only 72% of the long-term average precipitation for 2012 (Table 1) (Sidney, MT; USDC Commerce 1892-2012a). In 2012 through the month of June the LMNG had received just 49% precipitation when compared to the long term average for the area (Table 2). Precipitation in the GRNG was near the long-term average in 2011 and below the long-term average in 2012, at 103% and 72%; respectively (Table 3) (Lemmon, SD; USDC Commerce 2012b).

Table 2. Monthly precipitation (mm) for 2011, 2012, and long term average for plots located in the Little Missouri National Grasslands-McKenzie Ranger District (Sidney, MT; USDC Commerce 2012a).

Month	**2011**	**2012**	**Long-Term Average (1981-2010)**
January	34.0	2.5	10.4
February	15.0	5.3	8.4
March	31.0	1.3	15.2
April	74.2	39.1	26.7
May	151.6	18.8	51.6
June	38.4	27.2	71.1
July	72.1	69.8	64.0
August	17.5	22.6	29.5
September	24.1	1.8	31.8
October	12.4	56.9	27.9
November	8.9	6.9	14.0
December	2.5	10.9	13.2
Annual	481.8	263.1	363.7

Table 3. Monthly precipitation (mm) for 2011, 2012, and long term average for plots located in Grand River National Grasslands-Grand River Ranger District (Lemmon, SD; USDC Commerce 2012b).

Month	2011	2012	Long-Term Average (1981-2010)
January	11.4	5.8	8.9
February	24.1	8.9	11.9
March	21.6	12.4	25.9
April	85.3	68.1	47.0
May	101.1	43.9	71.9
June	78.0	36.8	72.9
July	48.5	84.1	71.1
August	53.8	38.9	51.1
September	7.1	2.0	36.1
October	38.4	16.8	34.0
November	0.5	7.6	18.0
December	4.6	5.3	10.9
Annual	474.4 (103%)	330.6 (72%)	459.7

Standing crop in both study locations was largely impacted by previous year's growth. In the LMNG current year's growth only contributed 56% of total standing crop, in the LMNG current year's growth accounted for 73% of total standing crop (Table 4). Exclusion of grazing as well as above average precipitation on the LMNG and GRNG (Table 2 and 3) may have contributed to the large percentage of previous year's growth observed on the exclosures. A significant reduction in standing crop was observed from the peak production collection period to the fall collection period across all sites and study locations (Table 5). In contrast mean biomass increased on each ecological site in the LMNG and as well as on the claypan sites on the GRNG (Table 5).

Table 4. Mean standing crop, biomass and visual obstruction reading for July 2012 collection in Little Missouri National Grasslands (LMNG) and Grand River National Grasslands (GRNG).

Study Area	Ecological Site	Standing Crop kg/ha	Biomass kg/ha	~ VOR cm
LMNG	Loamy	3,073	1,752	9.75
LMNG	Claypan	2,302	1,219	8.3
LMNG	Thin Loamy	1,966	1,204	8.44
GRNG	Loamy	2,914	2,244	10.51
GRNG	Claypan	2,492	1,729	10.72
GRNG	Thin Loamy	1,969	1,455	7.87

Table 5. Mean standing crop, biomass and visual obstruction reading for October 2012 with percentage change in production from July 2012 in Little Missouri National Grasslands (LMNG) and Grand River National Grasslands (GRNG).

Study Area	Ecological Site	Standing Crop kg/ha	Biomass kg/ha	VOR (cm)
LMNG	Loamy	2,440 (- 15.1 %)	1,945(+10.0%)	9.81 (+ 1.0 %)
LMNG	Claypan	1,885 (-18.2 %)	1,428(+15.0%)	7.98 (- 3.9 %)
LMNG	Thin Loamy	1,662 (-15.5 %)	1,414(+15.0%)	7.27 (- 14 %)
GRNG	Loamy	1,976 (-32.2 %)	1,757(-21.6%)	8.30 (- 23 %)
GRNG	Claypan	2,119 (-15 %)	1,825(+5.6%)	8.71 (- 17.1 %)
GRNG	Thin Loamy	1,505(-23.6 %)	1,189(-18.2%)	6.26 (- 20 %)

Plant Community Composition

The loamy sites on the LMNG were dominated by western wheatgrass and blue grama, contributing 33.5 and 19.4% of the total annual production, respectively. Four other species account for 28.2%, needle and thread, Kentucky bluegrass, green needlegrass, and fringed sagewort (*Artemisia frigida),* state 2.1 (Figure 2). The loamy sites on the GRNG were dominated by western wheatgrass at 23.7% and Kentucky bluegrass/Canada bluegrass (*Poa spp*.) at 24.2% of the total annual production, followed by blue grama at 15%, and needle grass at 14.7% of the total annual production, state 2.3 (Figure 2).

The claypan sites in the LMNG were dominated exclusively by western wheatgrass and blue grama at 50.3% and 19.7%; respectively, of the annual biomass in 2012, state 1.2 (Figure

3). The claypan sites on the GRNG had similar homogeneity with 3 species contributing nearly 74% of the total annual production; Kentucky bluegrass, 35.5%, western wheatgrass 21.6%, and blue grama 16.5% state 2.3 (Figure 3).

The thin loamy sites within the LMNG were dominated by little bluestem at 19% of the plant community by weight. Four other plant species; western wheatgrass, blue grama, needle-and-thread, and threadleaf sedge, contributed an additional 39% of the total annual production, state 2.1 (Figure 4). The thin loamy sites on the Grand River National Grasslands (GRNG) were dominated by threadleaf sedge and western wheatgrass with threadleaf sedge contributing to 19% of the overall production and western wheatgrass contributing 7%. No other species contributed greater than 5% to the overall production, state 3.3 (Figure 4).

Little Missouri National Grasslands

The loamy sites were the most productive throughout the study period, achieving the desired 8.89 cm (3.5 in.) in all but the spring 2012 collection period (Table 6). The mean standing crop declined ($P \leq 0.02$) by 15% from summer to fall 2012 collection periods. In contrast, the VOR did not change ($P > 0.05$) over this collection period.

The loamy ecological sites on the LMNG had a linear relationship between standing crop (SC) and VOR, with a coefficient of determination $R^2 = 0.54$, however, it was not significant ($P = 0.06$). The relationship between SC and VOR for fall 2012 was also linear $R^2 = 0.57$ (Figure 5).

Table 6. Mean visual obstruction reading (VOR) and mean standing crop (SC) for the loamy ecological sites in the Little Missouri National Grasslands – McKenzie District for all collection periods.

Sampling Period	Mean SC[1] (Kg/Ha)	SE	Mean[1] VOR (cm)	SE	Mean[1] VOR (in.)	SE
Spring 2012	NA	NA	8.21[a]	0.58	3.23[a]	0.23
Summer 2012	2501[a]	116.4	9.75[a]	0.68	3.84[a]	0.27
Fall 2012	2124[b]	156.1	9.81[a]	0.68	3.86[a]	0.27

[1] Means within column with similar superscript are not different ($P>0.05$).

The claypan sites on the LMNG failed to produce the desired 8.89 cm (3.5 in.) mean VOR during both the July and October collection periods (Table 7). The October VOR was similar (P>0.05) to the July 2012 collection period. In contrast, SC was 18% lower (P = 0.001) in October than July, 2012 (Table 5). The July collection period for claypan sites on the LMNG produced one of the strongest relationships between VOR and SC, with an R^2 = 0.93 (Figure 6). Similarly, the fall collection period had a coefficient of determination of r^2 = 0.81 (Figure 7).

Table 7. Mean visual obstruction reading (VOR) and standing crop (SC) for claypan ecological sites in the Little Missouri National Grasslands – McKenzie District for all collection periods.

Sampling Period	Mean SC (Kg/Ha)	SE	Mean VOR (cm)	SE	Mean VOR (in.)	SE
Spring 2012	NA	NA	7.49[a]	0.77	2.95[a]	0.30
Summer 2012	2302[a]	220.9	8.30[a]	1.01	3.27[a]	0.40
Fall 2012	1885[b]	245.3	7.98[a]	0.95	3.14[a]	0.37

[1] Means within column with similar superscript are not different (P>0.05).

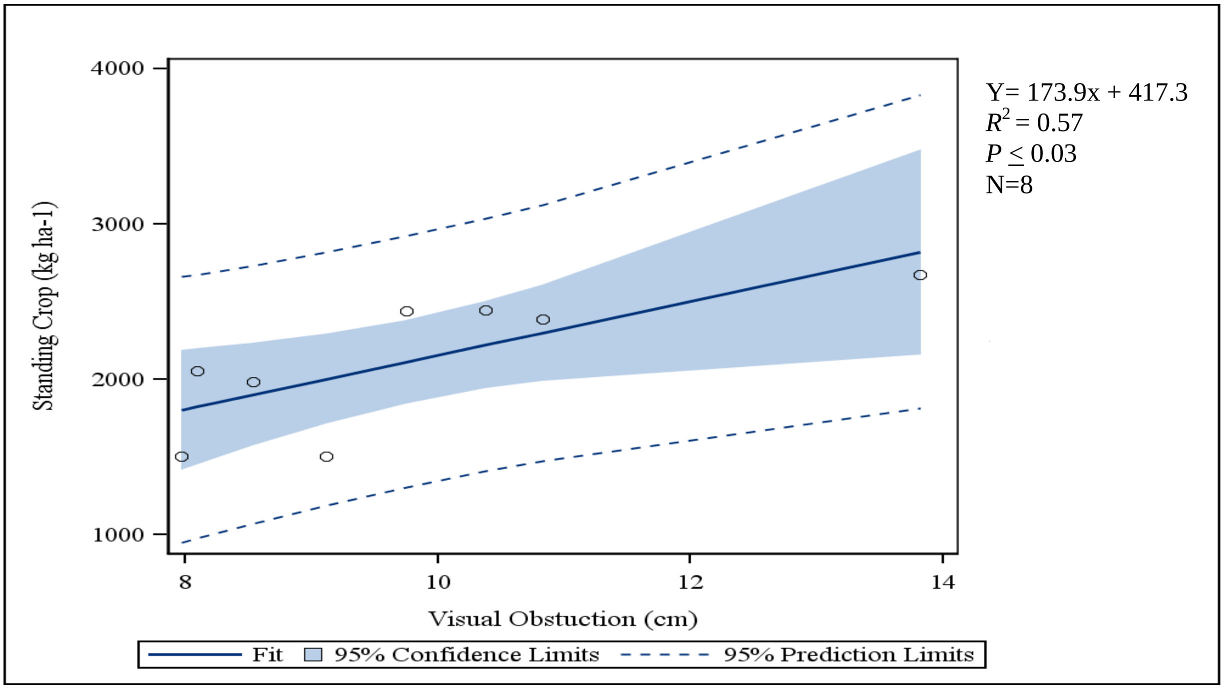

Figure 5. Linear regression model for the loamy ecological site on the Little Missouri National Grasslands – McKenzie Ranger District with associated regression model and 95% confidence and prediction limits for October, 2012 collection period**.**

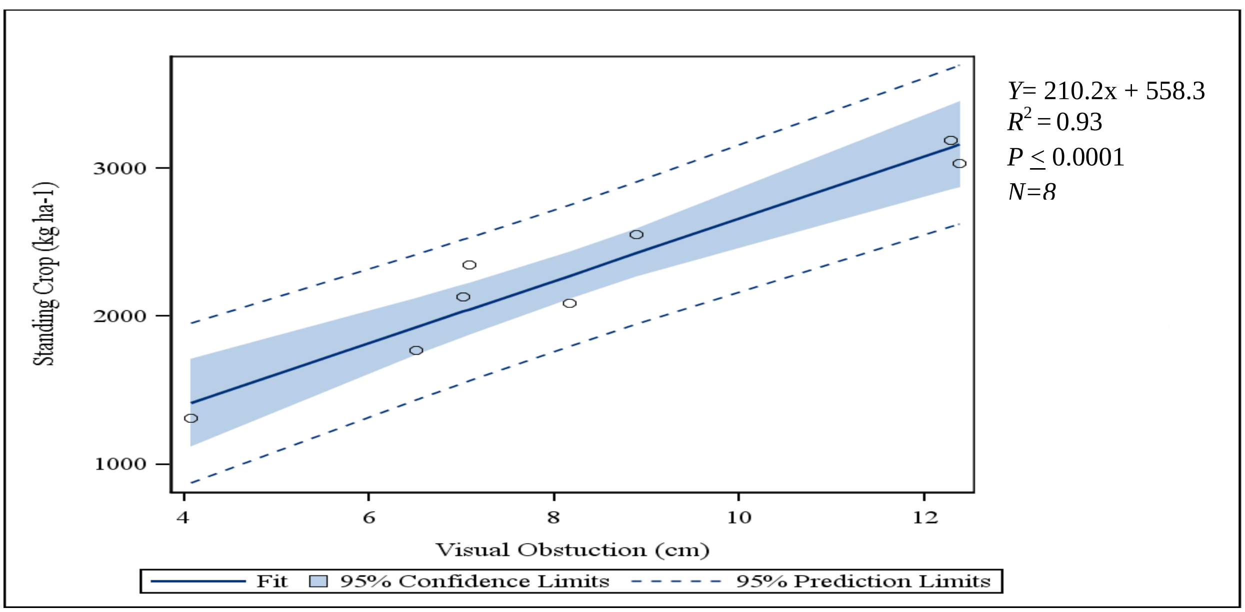

Figure 6. Linear regression model for the claypan ecological site on the Little Missouri National Grasslands – McKenzie Ranger District with associated regression model and 95% confidence and prediction limits for July, 2012 collection period.

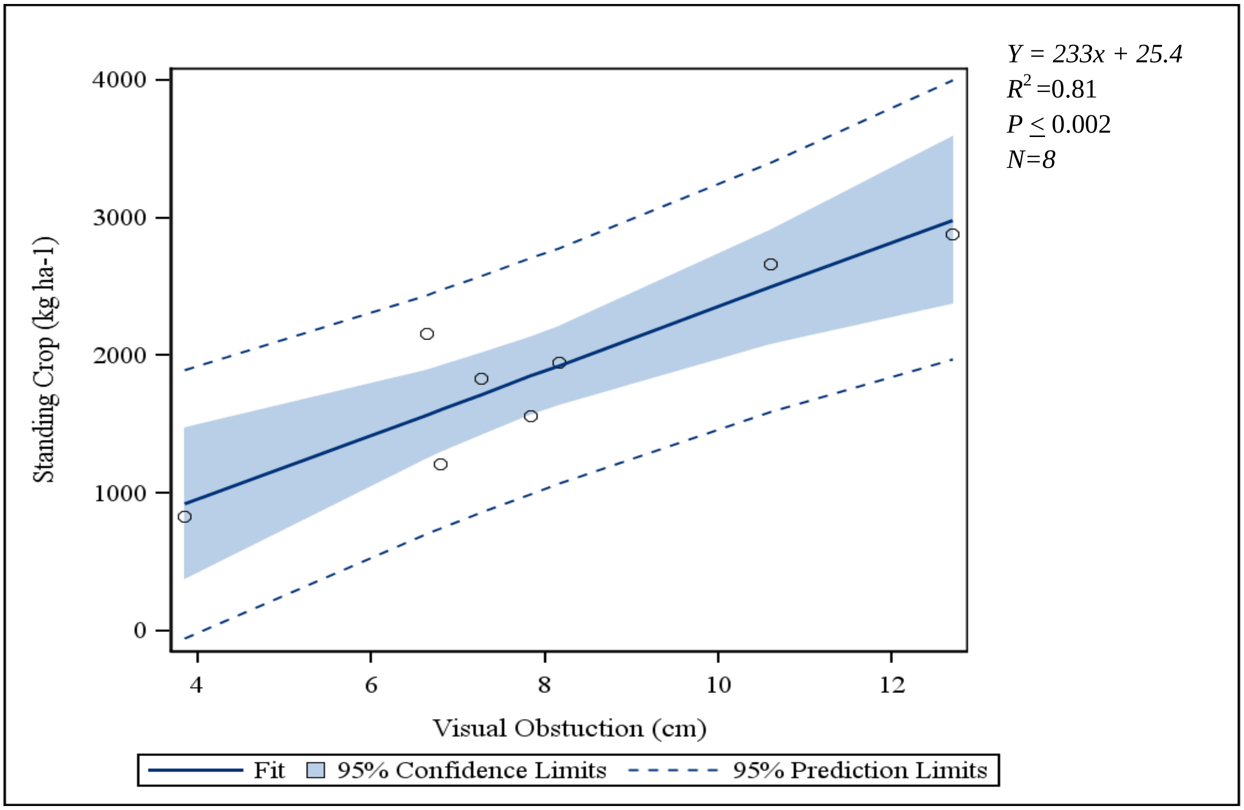

Figure 7. Linear regression model for the claypan ecological site on the Little Missouri National Grasslands – McKenzie Ranger District with associated regression model and 95% confidence and prediction limits for October, 2012 collection period.

The thin loamy ecological sites on the LMNG failed to achieve the desired VOR 8.89 cm (3.5 in.) structure for the fall of 2012 (Table 8). The VOR for the fall of 2012 was 14% lower ($P = 0.003$) than the summer 2012 collection period (Table 5). Standing crop was 15% lower during the fall 2012 collection period compared to the summer 2012 collection period, however, the difference was not significant ($P > 0.05$). The summer 2012 collection period for thin loamy ecological sites on the LMNG had a linear relationship between SC and VOR, with a coefficient of determination $R^2 = 0.85$ (Figure 8). The fall 2012 collection period for the thin loamy sites produced a coefficient of determination $R^2 = 0.58$ (Figure 9).

Table 8. Mean visual obstruction reading (VOR) and standing crop (SC) for thin loamy ecological sites in the Little Missouri National Grasslands – McKenzie District for all collection periods.

Collection Period	Mean SC (Kg/Ha)	SE	Mean VOR (cm)	SE	Mean VOR (in.)	SE
Spring 2012	NA	NA	7.22[a]	0.63	2.84[a]	0.25
Summer 2012	1966[a]	180.0	8.44[b]	0.97	3.32[b]	0.38
Fall 2012	1662[a]	222.2	7.27[a]	0.89	2.86[a]	0.35

[1] Means within column with similar superscript are not different (P>0.05).

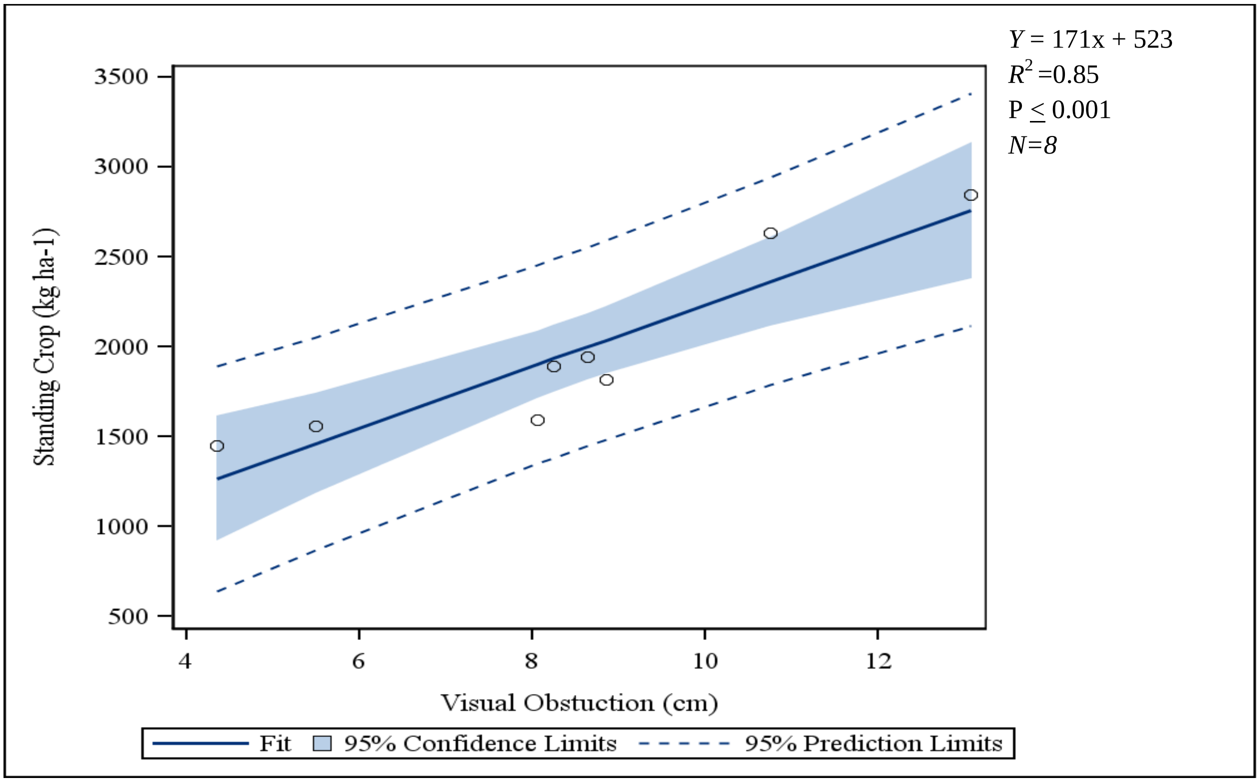

Figure 8. Linear regression model for the thin loamy ecological site on the Little Missouri National Grasslands – McKenzie Ranger District with associated regression model and 95% confidence and prediction limits for July, 2012 collection period.

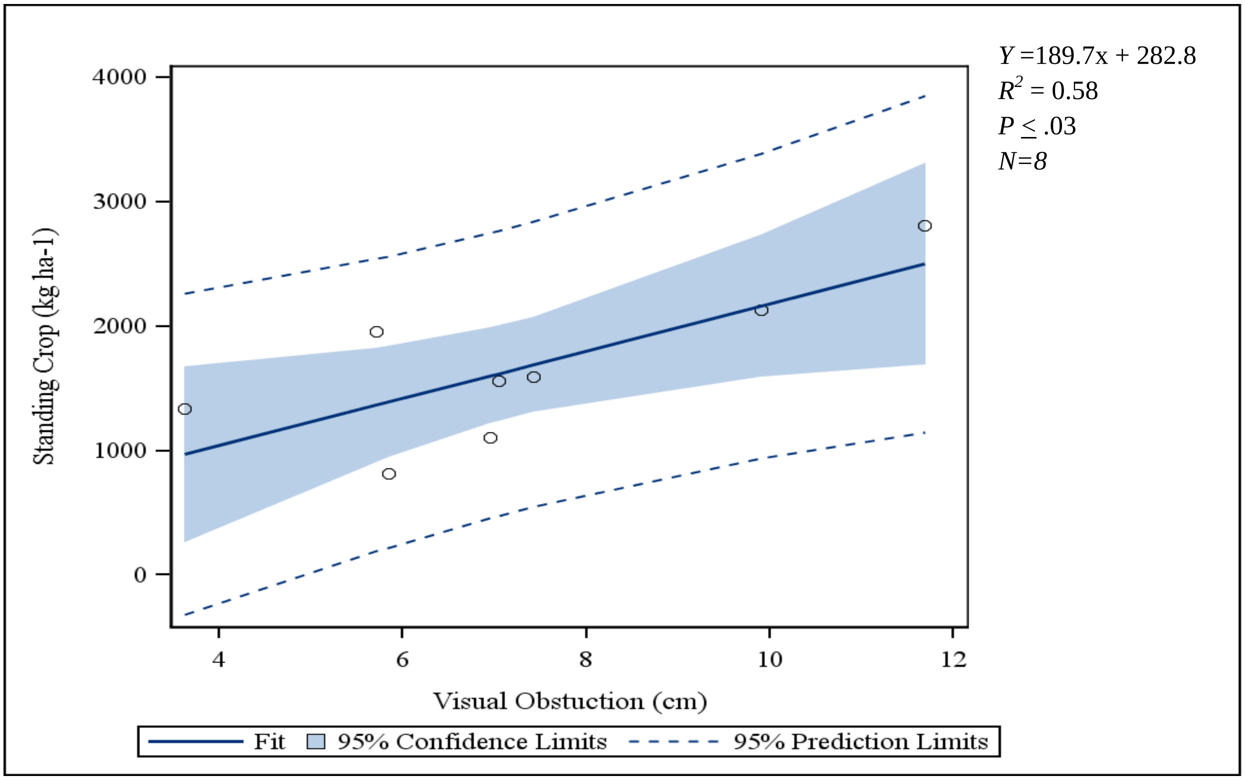

Figure 9. Linear regression model for the thin loamy ecological site on the Little Missouri National Grasslands – McKenzie Ranger District with associated regression model and 95% confidence and prediction limits for October, 2012 collection period.

Grand River National Grasslands

The loamy sites on the GRNG produced the desired 8.89 cm VOR during the summer 2012 collection period (Table 9). The fall 2012 VOR were reduced ($P \leq 0.05$) by 23% compared to the summer 2012 VORs. Similarly, standing crop was 32% less ($P = 0.004$) in the fall collection compared to summer 2012 collection period. The fall 2012 collection period for loamy ecological sites on the GRNG had a linear relationship between SC and VOR with a coefficient of determination $R^2 = 0.43$, however, it was not significant ($P > 0.05$). The relationship between SC and VOR during the summer 2012 collection period was $R^2 = 0.52$ ($P = 0.04$, Figure 10).

Table 9. Mean visual obstruction reading (VOR) and mean standing crop (SC) for the loamy ecological sites in the Grand River National Grasslands – Grand River District for all collection periods.

Sampling Period	Mean SC (Kg/Ha)	SE	Mean VOR (cm)	SE	Mean VOR (in.)	SE
Spring 2012	NA	NA	6.75[a]	0.67	2.66[a]	0.26
Summer 2012	2914[a]	208.3	10.72[b]	1.50	4.22[b]	0.59
Fall 2012	1976[b]	182.6	8.30[c]	0.63	3.27[c]	0.25

[1] Means within column with similar superscript are not different (P>0.05).

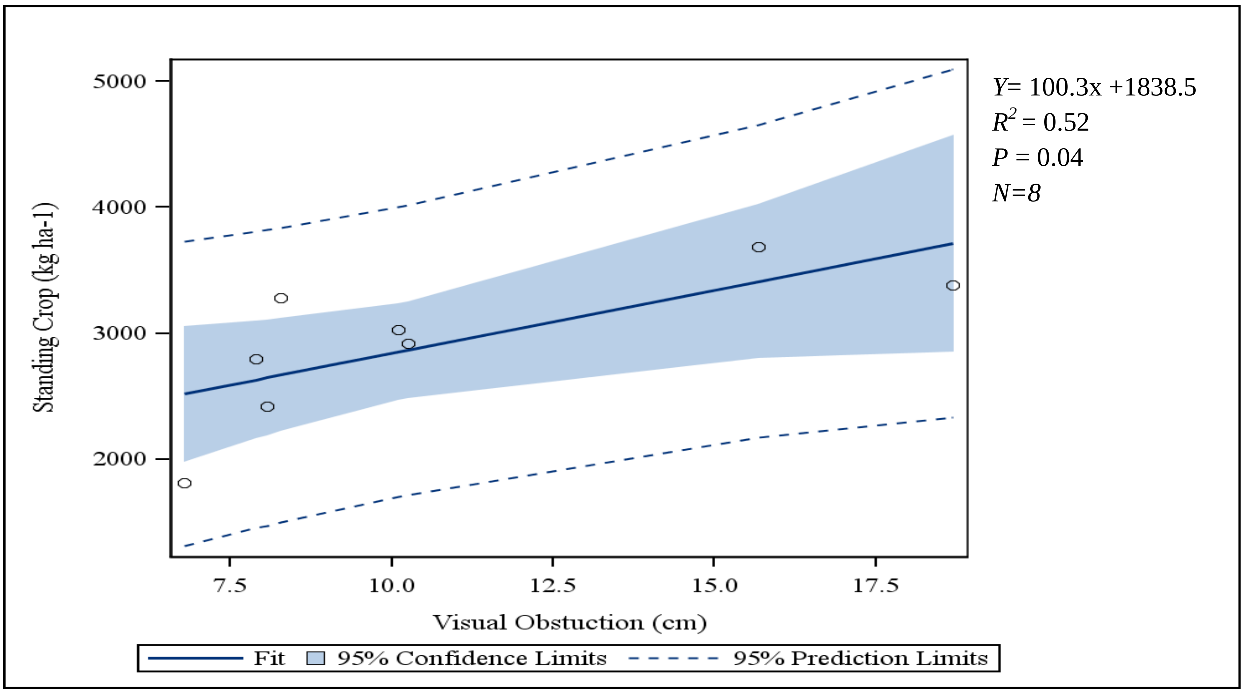

Figure 10. Linear regression model for the loamy ecological site on the Grand River National Grasslands – Grand River District with associated regression model and 95% confidence and prediction limits for July, 2012 collection period.

The claypan ecological site produced the desired VOR 8.89 cm structure for the summer 2012 collection period (Table 10). A 17.1% loss ($P \leq 0.05$) in VOR was observed from the summer to fall 2012 collection period. Similarly, SC decreased by 15% ($P \leq 0.05$) from summer to fall of 2012.

The fall 2012 collection period for claypan ecological sites on the GRNG had a strong linear relationship between SC and VOR with a coefficient of determination of $r^2 = 0.96$ (Figure 11). The relationship between SC and VOR for the summer 2012 was $r^2 = 0.40$ and not significant for this collection period ($P \geq 0.05$).

Table 10. Mean visual obstruction reading (VOR) and mean standing crop (SC) for the claypan ecological sites in the Grand River National Grasslands – Grand River District for all collection periods.

Sampling Period	Mean SC (Kg/Ha)	SE	Mean VOR (cm)	SE	Mean VOR (In.)	SE
Spring 2012	NA	NA	8.38[a]	0.55	3.30[a]	0.22
Summer 2012	2492[a]	143.1	10.51[b]	1.00	4.14[b]	0.39
Fall 2012	2119[b]	165	8.71[a]	0.47	3.43[a]	0.19

[1] Means within column with similar superscript are not different (P>0.05).

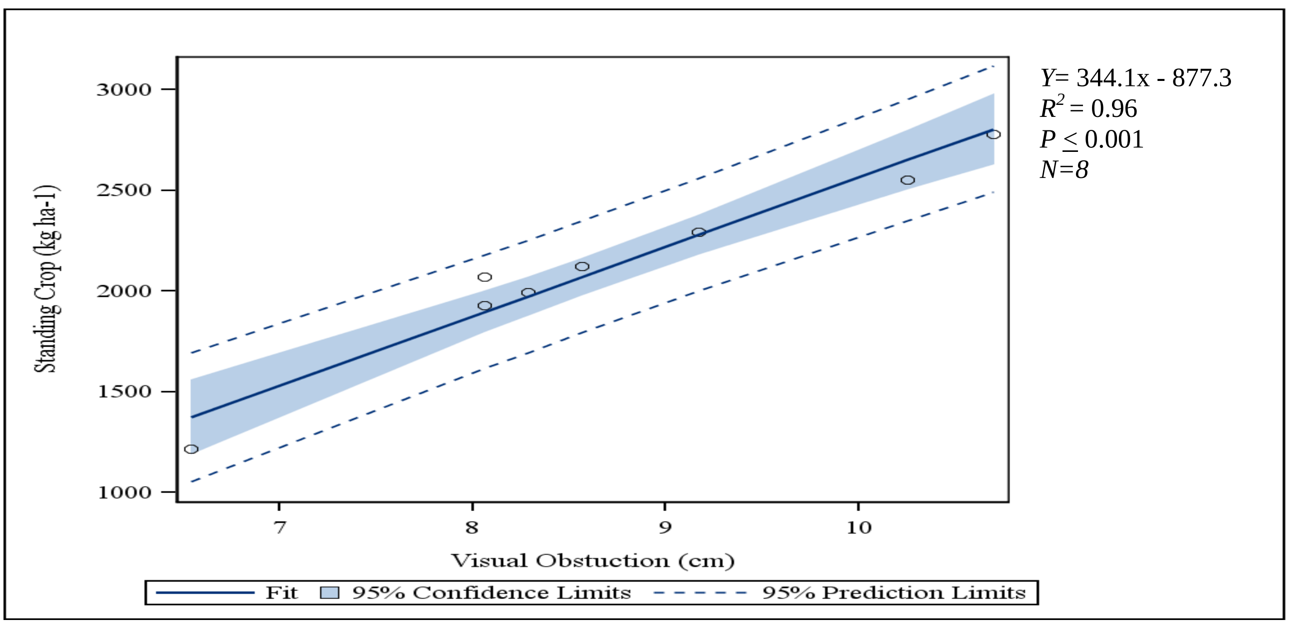

Figure 11. Linear regression model for the claypan ecological site on the Grand River National Grasslands – Grand River District with associated regression model and 95% confidence and prediction limits for October, 2012 collection period.

The thin loamy sites on the GRNG did not produce the desired 8.89 cm VOR during any of the collection periods, with the summer of 2012 being the highest at 7.87 cm (Table 11). The fall 2012 VOR were 20% lower than the summer 2012 VOR ($P \leq 0.05$). Standing crop was 24% lower during the fall 2012 period compared to the summer ($P \leq 0.05$). The fall 2012 collection period for thin loamy ecological sites on the GRNG had a linear relationship ($P \leq 0.05$) between SC and VOR with a coefficient of determination $r^2 = 0.54$ (Figure 12). The summer 2012 collection period for the thin loamy sites produced a coefficient of determination $r^2 = 0.63$ ($P \leq 0.05$, Figure 13).

Table 11. Mean visual obstruction reading (VOR) and mean standing crop (SC) for the thin loamy ecological sites in the Grand River National Grasslands – Grand River District for all collection periods.

Sampling Period	Mean SC (Kg/Ha)	SE	Mean VOR (cm)	SE	Mean VOR (in.)	SE
Spring 2012	NA	NA	5.75[a]	0.59	2.26[a]	0.23
Summer 2012	1969[a]	155.73	7.87[b]	0.89	3.10[b]	0.35
Fall 2012	1505[b]	169.2	6.26[a]	0.66	2.46[a]	0.26

[1] Means within column with similar superscript are not different (P>0.05).

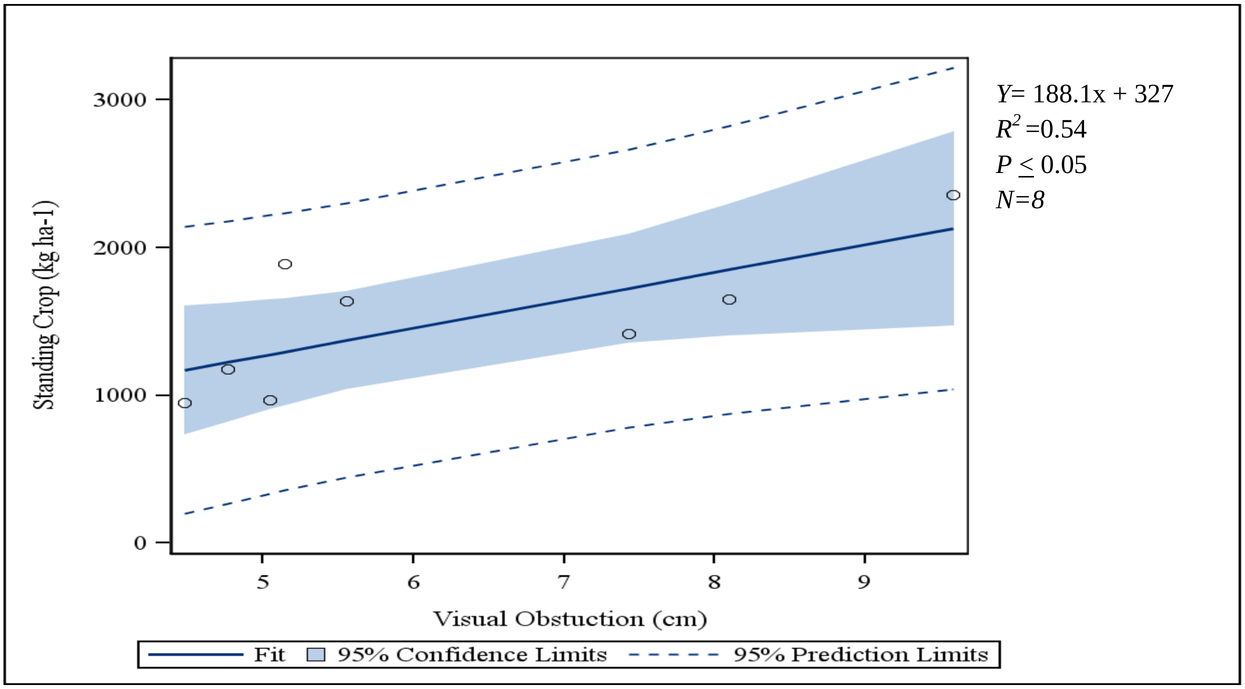

Figure 12. Linear regression model for the thin loamy ecological site on the Grand River National Grasslands – Grand River District with associated regression model and 95% confidence and prediction limits for October, 2012 collection period.

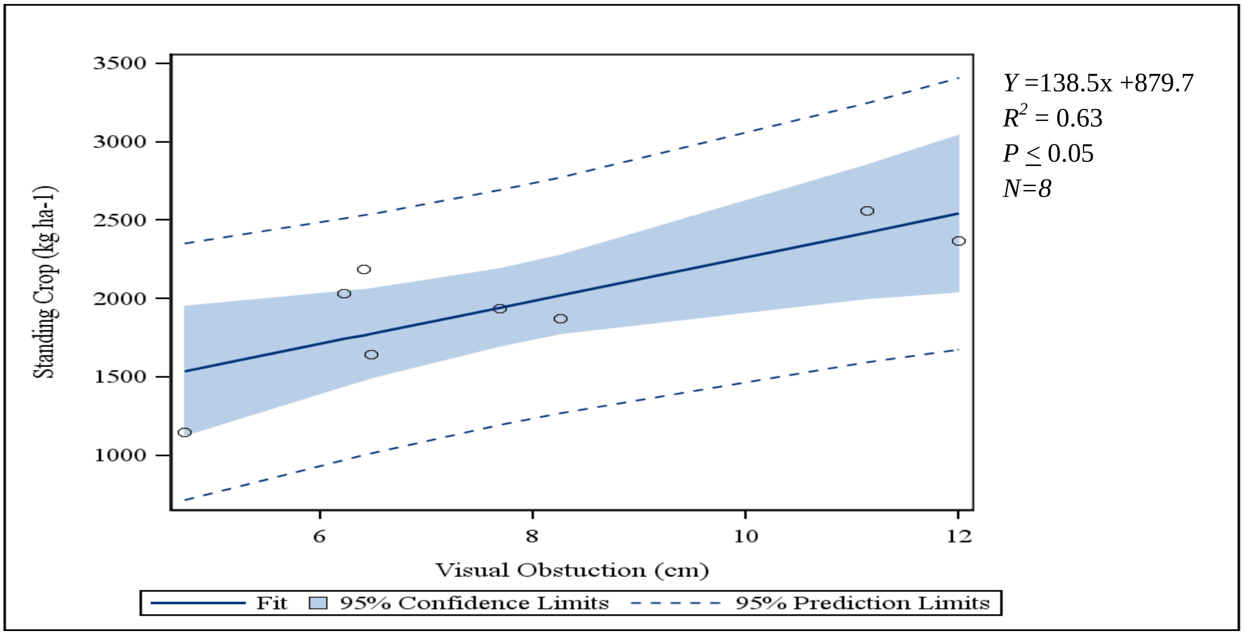

Figure 13. Linear regression model for the thin loamy ecological site on the Grand River National Grasslands – Grand River District with associated regression model and 95% confidence and prediction limits for July, 2012 collection period.

DISCUSSION

Two locations within the Dakota Prairie Grasslands (DPG), Little Missouri National Grasslands (LMNG) and Grand River National Grasslands (GRNG), were studied to determine if they were biologically capable of producing 3.5 inches (8.89 cm) VOR (high structure) during peak herbage production (July) and at or near the end of the grazing season (October) on select ecological sites under a no livestock grazing scenario. Only the loamy ecological site at both study sites and claypan at GRNG were biologically capable of meeting the criteria of the USFS during the peak herbage production period. Only the loamy ecological site on the LMNG was biologically capable of producing 3.5 inches (8.89 cm) during the October period. The thin loamy and claypan ecological sites were not capable of producing 3.5 inches (8.89 cm) at either study sites during the October collection period.

Whoel (2010) reported mean VOR from loamy, clayey, and sandy ecological sites in the LMNG and GRNG with none to slight grazing to be less than 8.89 cm (3.5 inches) during the period mid-June to mid-August. Similarly, Vader (2000) reported a mean VOR of 6.02 cm (2.44 inches) and 6.5 cm (2.63 inches) on the shallow and loamy ecological range sites; respectively, with none to slight grazing in the LMNG. However, Vader (2000) showed a mean VOR of 24.06 cm (9.74 inches) on the loamy overflow ecological site with none to slight grazing.

The use of exclosures to eliminate the livestock grazing variable did provide a stronger correlation in the mixed grass prairie on the LMNG and GRNG when compared to the results obtained in a similar study in the same location without exclosures (Whoel 2010). A significant relationship existed between VOR and standing crop (SC) in each of the ecological sites in both study areas; however, the correlations were not consistent.

In contrast to Vader's (2000) study where she reported a strong height to weight correlation ($r^2 = 0.69$) on the loamy ecological site during the summer period, we found a poor relationship with the loamy sites during the summer collection period in the GRNG and loamy sites on the LMNG during the fall collection period. The loamy sites on the GRNG in the fall and loamy sites in the LMNG summer did not produce significant relationships ($P>0.05$). The poor relationships observed on the loamy sites is likely due to the heterogeneous nature of those sites. A stronger correlation ($r^2 >0.6$) was observed on the claypan sites during both collection periods on the LMNG and the fall collection period on the GRNG. The summer collection period in the GRNG on the claypan sites did not generate a significant relationship ($P>0.05$). The strong relationship observed on the claypan ecological sites was likely due to the homogenous plant community on these sites (Jackson and Paine 2006). A weak correlations was observed ($r^2 <0.6$) on the thin loamy sites during the fall collection period in both the GRNG and the LMNG. However, we observed a strong height to weight relationship ($r^2 > 0.6$) on the thin loamy sites during the summer collection period on both the LMNG and GRNG. The strong correlations observed during peak production on the thin loamy sites may be due to the reduced influence of little bluestem during this collection period as opposed to the fall collection period. As a warm season grass, little bluestem would have significant growth following the July collection period to the October collection period.

The inconsistencies observed in our study have also been reported by other researchers. In the Nebraska Sandhills region, Benkobi et al. (2000) reported an r^2 *of 0.88*, while Voleskey et al. (1999) reported an r^2 *of 0.41*. Vader (2000) reported an r^2 of *0.37, 0.61*, and *0.69* on shallow, overflow, and loamy ecological sites; respectively, in western North Dakota. While some researchers failed to produce a strong linear relationship ($r^2<0.6$) between VOR and SC

(Volesky et al. 1999; Vader 2000; Woehl 2010), most have achieved positive results ($r^2 > 0.6$) (Robel et al. 1970; Benkobi et al 2000; Vader 2000; Vermeire and Gillen 2001; Vermeire et al. 2002; Uresk 2012).

The criteria of the USFS high structure 8.89 cm (3.5 inches) was achieved in our study when standing crop at peak production was greater than 2492 kg/ha. Our models indicated that 2600 kg/ha at peak production was required in order to achieve high structure in the fall. Standing crop in both study locations was largely impacted by previous year's growth. In the LMNG current year's growth only contributed 55% of total standing crop (Table 3), while in the LMNG current year's growth accounted for 73% of total standing crop (Table 4). Exclusion of grazing as well as above average precipitation on the LMNG and GRNG (Table 3 and 4) may have contributed to the large percentage of previous year's growth observed on the exclosures. A significant reduction in standing crop was observed from peak production to October across all sites and study locations (Table 3 and 4). Sedivec et al. (2009) and Sedivec et al. (2010) reported a 30% and 34% reduction in standing crop for cool- and warm-season grasses; respectively, in the fall compared to peak production. Standing crop required to achieve high structure 8.89 cm (3.5 inches) based on models varied significantly among researchers, ranging from 1177 kg/ha (Vermeire and Gillen 2001) to 3341 kg/ha (Vader 2000). The mean standing crop required to reach high structure based on models from 22 different studies was 2022 kg/ha (Volesky et al. 1999; Benkobi et a. 2000; Vader 2000; Vermeire and Gillen 2001; Vermeire et al. 2002; Uresk and Benzon 2007; Uresk and Junti 2008; Woehl 2010; Uresk 2012). The mean standing crop required to achieve high structure 8.89 cm in our study was similar to those observed by other researchers at 2334 kg/ha from our July collection period and 2080 kg/ha from our fall collection period.

When comparing the mean VOR, the claypan and loamy sites were capable of producing high structure 8.89 cm (3.5 inches) when livestock grazing was eliminated. However, the question remains at what level of grazing is high structure attainable. Whoel (2010) reported a mean VOR of 6.0 cm (2.36 in), 5.73 cm (2.25 in), 5.19 cm (2.04 in) on loamy, clayey, and sandy; respectively, on the LMNG and the GRNG during peak production from 2007 through 2009 with none to slight grazing pressure. Vader (2000) reported mean VOR of 6.02 cm (2.37 in), 6.5 cm (2.56 in), and 24.06 cm (9.47) on shallow, loamy and loamy overflow ecological sites; respectively, during peak production on the LMNG with none to slight grazing pressure.

The ability of these ecological sites to achieve high structure 8.89 cm is largely dependent on precipitation. Both the LMNG and the GRNG received above average precipitation for 2011, however, both were below average for 2012. The LMNG was impacted greater than the GRNG receiving only 72% of the long term average with much of that following during the July collection period. Numerous studies in the Northern Great Plains have reported a positive relationship between precipitation and forage production (Smoliak 1986, Sala et al, 1988). On overflow ecological sites in south-central North Dakota, Patton et al. (2007) reported production was greater on grazed treatments than on un-grazed treatments when precipitation was greater than 248.4 mm from the end of the growing season in the previous year to the end of the grazing season in the current year. Smoliak (1986) found that the strongest correlation between forage production and precipitation occurred when accounting for precipitation from the previous September plus current year April through July.

Plots for this study were selected to meet production and species nearest to the HCPC as possible. Habitat types such as crested wheatgrass sites that do not meet the criteria for the HCPC may have the ability to produce high structure 8.89 cm. In terms of nest quality, structure is considered of greater importance than species composition for sharp tailed grouse nesting hens (Houchen 2011; Hamerstrom et al. 1957).

SUMMARY AND CONCLUSION

Visual obstruction readings have traditionally been used to estimate standing crop in relation to nesting bird habitat. Our study had two objectives both without livestock grazing: 1) to evaluate the biological capabilities of three specific ecological sites (loamy, thin loamy, and claypan) in the Little Missouri National Grasslands (LMNG) and Grand River National Grasslands (GRNG), and 2) evaluate the relationship on these sites between VOR and standing crop. The USDA Forest Service has set the desired VOR for the three ecological sites at 8.89 cm (3.5 inches) following the grazing season. Only the loamy ecological site was capable of producing a mean 8.89 cm (3.5 inches) during the October collection period with no livestock grazing. The claypan ecological site was only capable of producing a mean 8.89 cm (3.5 inches) during the October collection period when the SE was added to the mean VOR (3.51 inches on the LMNG, 3.62 inches on the GRNG) and with no grazing. The thin loamy ecological site failed to produce a mean 3.5 inches (8.89 cm) following the grazing season, only achieving it during the summer collection period on the LMNG. Across all sites, mean standing crop was 20% lower in October compared to peak standing crop in July on this study.

A significant relationship existed between VOR and standing crop for each of the ecological sites in both study areas; however, the correlation was inconsistent and varied by time of season and ecological site. The use of exclosures to eliminate livestock grazing did create a stronger correlation in the mixed grass prairie on the LMNG and GRNG when compared to the results obtained in a similar study on the same location when livestock grazing occurred (Whoel 2010). The strongest correlation existed between VOR and standing crop on the claypan site. The weakest correlation was observed on the loamy sites. The Dakota Prairie National Grassland has a multi-use purpose that includes livestock production and wildlife habitat in the region. With proper management, livestock and wildlife can co-exist on these diverse grasslands. The VOR has the potential to provide land managers with valuable data and aid in their decision making; however, further research is needed to establish a reliable relationship between VOR and standing crop on the mixed grass prairie.

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APPENDIX A

Loamy Ecological site species list by scientific name and kg/ha for each transect in the Little Missouri National Grasslands

Scientific Name	**Common Name**	LM-1	LM-2	LM-3	LM-4
Achillea millefolium	Western yarrow	0.0	1.2	23.9	6.3
Aristida purpurea	Purple threeawn	4.3	0.0	0.0	0.0
Artemisia cana	Silver sagebrush	23.7	0.0	0.0	0.0
Artemisia frigida	Prairie sagewort	12.7	41.0	21.1	0.0
Artemisia ludoviciana	White sagebrush	0.0	0.0	0.0	12.3
Bouteloua gracilis	Blue grama	93.5	473.9	195.0	160.3
Bouteloua dactyloides	Buffalograss	0.0	0.0	0.0	13.0
Calamagrostis montanensis	Plains reedgrass	0.0	8.3	0.0	3.0
Carex filifolia	Threadleaf sedge	0.0	1.0	0.0	1.0
Carex inops	Sun sedge	0.0	41.3	0.0	0.0
Hesperostipa comata	Needle-and-thread	48.6	248.5	52.5	0.0
Koeleria macrantha	Prairie junegrass	4.8	7.2	26.3	29.5
Lactuca tatarica	Blue lettuce	0.0	2.2	0.0	0.0
Lygodesmia juncea	Rush skeletonplant	0.0	11.4	0.0	0.0
Nassella viridula	Green needlegrass	0.0	72.4	19.7	274.7
Oligoneuron rigidum	Stiff goldenrod	0.0	0.0	0.0	14.7
Pascopyrum smithii	Western wheatgrass	525.5	401.2	388.5	574.9
Poa pratensis	Kentucky bluegrass	24.6	313.0	34.9	144.4
Poa secunda	Sandberg's bluegrass	0.0	0.0	269.0	0.0
Polygala alba	White milkwort	21.6	7.4	0.0	0.0
Ratibida columnifera	Prairie coneflower	2.5	9.3	0.0	22.8
Solidago missouriensis	Missouri goldenrod	0.1	0.0	0.0	0.0
Sphaeralcea coccinea	Scarlet globemallow	0.0	0.0	2.7	0.0
Symphoricarpos occidentalis	Western snowberry	0.0	0.0	0.0	44.7

Scientific Name	**Common Name**	LM-5	LM-6	LM-7	LM-8
Achillea millefolium	Western yarrow	0.0	0.0	0.0	2.1
Aristida purpurea	Purple threeawn	0.0	0.0	49.1	12.2
Artemisia frigida	Prairie sagewort	5.7	0.0	119.7	284.4
Astragalus purshii	Wollypod milkvetch	0.0	0.0	0.0	8.8
Bouteloua curtipendula	Sideoats grama	8.5	0.0	0.0	0.0
Bouteloua gracilis	Blue grama	69.3	226.9	268.9	354.4
Calamovilfa longifolia	Prairie sandreed	0.7	0.0	0.0	0.0
Calamagrostis montanensis	Plains reedgrass	1.6	0.0	0.0	27.1
Carex duriuscula	needleleaf sedge	0.0	0.0	81.4	0.0
Carex filifolia	Threadleaf sedge	0.0	0.0	24.8	17.5
Carex inops	Sun sedge	0.0	0.0	34.2	34.3
Echinacea angustifolia	Black samson	10.2	0.0	333.4	1.1
Elymus lanceolatus	Thickspike wheatgrass	0.0	0.0	55.4	0.0
Gutierrezia sarothrae	Broom snakeweed	0.0	0.0	35.5	0.0
Hesperostipa comata	Needle-and-thread	97.1	13.0	255.7	130.1
Koeleria macrantha	Prairie junegrass	0.0	0.0	28.0	38.4
Krascheninnikovia lanata	Winterfat	147.8	0.0	0.0	0.0
Lactuca tatarica	Blue lettuce	0.0	0.0	2.4	0.2
Lithospermum incisum	Narrowleaf stoneseed	0.0	0.0	0.0	2.0
Lygodesmia juncea	Rush skeletonplant	0.0	0.0	2.0	0.0
Muhlenbergia cuspidata	Plains muhly	0.0	0.0	0.0	11.6
Nassella viridula	Green needlegrass	94.3	127.2	0.0	54.7
Oxytropis lambertii	Purple locoweed	0.0	0.0	15.0	0.0
Pascopyrum smithii	Western wheatgrass	496.3	441.7	129.4	220.1
Poa pratensis tensis	Kentucky bluegrass	2.9	0.0	0.0	191.9
Polygala alba	White milkwort	36.6	0.0	0.0	0.0
Ratibida columnifera	Prairie coneflower	0.0	0.0	3.1	0.0
Sphaeralcea coccinea	Scarlet globemallow	0.4	0.1	7.5	0.0
Symphyotrichum ericoides	Heath aster	0.0	0.0	19.4	0.0
Symphyotrichum laeve	Smooth blue aster	73.5	0.0	0.0	0.0
Symphoricarpos occidentalis	Western snowberry	6.7	0.0	0.0	0.0
Tragopogon dubius	Goatsbeard	0.0	0.0	7.7	13.9

APPENDIX B

Claypan Ecological site species list by scientific name and kg/ha for each transect in the Little Missouri National Grasslands**.**

Scientfic Name	**Common Name**	CP-1	CP-2	CP-3	CP-4
Achillea millefolium	Western yarrow	0.0	0.0	0.0	2.8
Aristida purpurea	Purple threeawn	0.0	0.0	0.0	7.3
Artemisia ludoviciana	White sagebrush	0.0	0.0	0.0	0.0
Bouteloua gracilis	Blue gramma	59.5	87.4	92.7	642.2
Bouteloua dactyloides	Buffalograss	0.0	41.8	0.0	0.0
Carex filifolia	Threadleaf sedge	19.8	0.0	0.0	0.0
Gaura coccinea	Scarlet beeblossom	0.8	0.0	0.0	0.0
Gutierrezia sarothrae	Broom snakeweed	0.0	6.4	0.0	99.7
Hesperostipa comata	Needle-and-thread	168.7	2.7	0.0	0.0
Koeleria macrantha	Prairie junegrass	11.4	0.0	7.2	0.0
Lactuca tatarica	Blue lettuce	0.8	0.0	0.0	0.0
Linum perenne	Blue flax	6.0	0.0	0.0	0.0
Muhlenbergia cuspidata	Plains muhly	0.0	2.6	99.6	0.0
Nassella viridula	Green needlegrass	69.1	3.1	16.1	81.1
Opuntia fragilis	Brittle pricklypear	0.0	102.9	0.0	0.0
Opuntia polyacantha	Plains pricklypear	0.0	512.8	0.0	0.0
Pascopyrum smithii	Western wheatgrass	708.8	330.7	1005.8	524.2
Poa pratensis	Kentucky bluegrass	17.4	0.0	0.0	17.2
Polygala alba	White milkwort	60.1	0.0	0.0	0.0
Ratibida columnifera	Prairie coneflower	37.5	0.0	38.1	1.9
Scarlet globemallow	Scarlet globemallow	0.0	2.2	0.0	0.0
Symphyotrichum laeve	Smooth blue aster	0.0	8.8	0.0	0.0
Symphoricarpos occidentalis	Western snowberry	35.3	0.0	0.0	0.0
Zizia aptera	Meadow zizia	0.1	0.0	0.0	0.0

Scientfic Name	**Common Name**	CP-5	CP-6	CP-7	CP-8
Achillea millefolium	Western yarrow	1.0	1.2	15.1	0.3
Aristida purpurea	Purple threeawn	118.2	0.0	0.3	0.0
Artemisia frigida	Prairie sagewort	0.0	0.7	16.5	0.0
Artemisia ludoviciana	White sagebrush	0.0	0.0	0.0	33.7
Bouteloua gracilis	Blue gramma	222.7	41.7	73.6	686.0
Bromus inermis	Smooth brome	0.0	34.5	0.0	0.0
Calamagrostis montanensis	Plains reedgrass	38.3	0.0	0.0	0.0
Carex filifolia	Threadleaf sedge	0.0	0.0	0.0	9.5
Comandra umbellata	Bastard toadflax	0.0	24.2	0.0	0.0
Distichlis spicata	Inland saltgrass	118.3	0.0	1.6	24.1
Echinacea angustifolia	Black samson	23.5	0.0	0.0	0.0
Elymus lanceolatus	Thickspike wheatgrass	0.0	74.8	0.0	0.0
Gutierrezia sarothrae	Broom snakeweed	32.5	115.8	0.0	17.7
Hesperostipa comata	Needle-and-thread	0.0	0.0	120.3	0.0
Koeleria macrantha	Prairie junegrass	5.4	49.7	0.0	0.0
Krascheninnikovia lanata	Winterfat	0.0	13.0	0.0	0.0
Muhlenbergia cuspidata	Plains muhly	72.9	0.0	0.0	0.0
Nassella viridula	Green needlegrass	0.0	80.2	39.0	0.0
Pascopyrum smithii	Western wheatgrass	396.8	238.8	746.7	921.8
Poa pratensis	Kentucky bluegrass	14.8	154.6	12.4	0.0
Poa species	Poa species	0.0	0.0	46.7	0.0
Ratibida columnifera	Prairie coneflower	0.0	0.0	0.0	25.9
Rosa arkansana	Prairie rose	0.0	11.0	0.0	0.0
Schizachyrium scoparium	Little bluestem	14.7	0.0	0.0	0.0
Solidago missouriensis	Missouri goldenrod	39.3	0.0	0.0	0.0
Scarlet globemallow	Scarlet globemallow	0.0	0.0	0.0	0.2
Symphyotrichum falcatum	White prairie aster	0.0	0.0	9.3	0.0
Symphyotrichum laeve	Smooth blue aster	10.0	0.0	0.0	0.0
Symphoricarpos occidentalis	Western snowberry	0.0	1.5	0.0	0.0
Unknown Forb	Unknown Forb	0.0	0.0	11.6	0.0

APPENDIX C

Thin Loamy Ecological site species list by scientific name and kg/ha for each transect in the Little Missouri National Grasslands.

Scientfic Name	**Common Name**	TL-1	TL-2	TL-3	TL-4
Antennaria neglecta	Field pussytoes	0.0	17.6	0.0	0.0
Antennaria parvifolia	Small-leaf pussytoes	0.0	6.8	0.0	0.0
Aristida purpurea	Purple threeawn	0.0	0.0	6.7	0.0
Artemisia cana	Silver sagebrush	84.4	0.0	0.0	0.0
Artemisia frigida	Prairie sagewort	5.5	6.6	0.7	3.9
Artemisia ludoviciana	White sagebrush	0.0	9.7	0.0	30.7
Astragalus missouriensis	Missouri milkvetch	5.8	0.0	0.0	0.0
Bouteloua curtipendula	Sideoats grama	110.8	32.3	32.6	15.2
Bouteloua gracilis	Blue gramma	64.4	8.5	10.5	119.5
Calamovilfa longifolia	Prairie sandreed	50.8	57.2	92.1	0.0
Carex filifolia	Threadleaf sedge	206.6	83.1	346.3	109.5
Carex inops	Sun sedge	0.0	0.0	0.0	26.0
Calamovilfa longifolia	Prairie sandreed	0.0	0.0	0.0	66.2
Distichlis spicata	Inland saltgrass	0.0	18.6	0.0	0.0
Echinacea angustifolia	Black samson	19.6	1.5	12.4	0.0
Hard Seed Gromwell	Hard Seed Gromwell	0.0	0.0	4.5	0.0
Helianthus pauciflorus	Stiff sunflower	10.6	5.0	0.0	0.0
Hesperostipa comata	Needle-and-thread	6.0	68.0	86.6	225.5
Hesperostipa spartea	Porcupine grass	7.7	0.0	0.0	0.0
Juniperus horizontalis	Creeping juniper	292.8	0.0	0.0	0.0
Koeleria macrantha	Prairie junegrass	0.0	27.0	0.0	0.0
Krascheninnikovia lanata	Winterfat	0.0	127.2	0.0	0.0
Lygodesmia juncea	Rush skeletonplant	0.0	0.0	0.7	4.5
Muhlenbergia cuspidata	Plains muhly	109.4	52.0	9.6	0.0
Nassella viridula	Green needlegrass	11.5	9.3	19.3	0.0
Pascopyrum smithii	Western wheatgrass	284.9	138.7	77.5	99.6
Poa pratensis	Kentucky bluegrass	41.9	0.0	0.0	15.0
Polygala alba	White milkwort	15.7	2.8	0.2	0.0
Rosa arkansana	Prairie rose	0.0	0.0	3.2	9.1
Schizachyrium scoparium	Little bluestem	337.7	78.8	73.6	367.1
Solidago missouriensis	Missouri goldenrod	0.0	0.0	15.9	0.0
Symphyotrichum falcatum	White prairie aster	0.0	8.3	0.0	0.0
Symphyotrichum laeve	Smooth blue aster	13.3	17.2	2.2	0.0
Symphoricarpos occidentalis	Western snowberry	0.0	0.0	0.0	51.1

Scientfic Name	**Common Name**	TL-5	TL-6	TL-7	TL-8
Agropyron cristatum	Crested wheatgrass	0.0	0.0	0.0	402.4
Aristida purpurea	Purple threeawn	69.2	0.0	140.9	0.0
Artemisia dracunculus	Tarragon	0.0	39.5	0.0	0.0
Arabis suffrutescens	Woody rockcress	0.0	0.0	1.8	0.0
Artemisia frigida	Prairie sagewort	2.5	0.0	4.0	18.9
Symphyotrichum oblongifolium	Aromatic aster	72.5	5.6	9.2	0.0
Astragalus pauperculus	Depauperate milkvetch	3.8	0.0	0.0	0.0
Astragalus purshii	Wollypod milkvetch	4.4	12.0	4.3	0.0
Bouteloua curtipendula	Sideoats grama	202.9	86.4	0.0	0.0
Bouteloua gracilis	Blue gramma	0.0	356.2	29.3	72.4
Bromus inermis	Smooth brome	0.0	0.0	5.9	0.0
Calamovilfa longifolia	Prairie sandreed	0.0	0.0	4.5	0.0
Calamagrostis montanensis	Plains reedgrass	0.0	0.0	0.0	12.1
Carex filifolia	Threadleaf sedge	0.0	49.2	74.0	82.1
Carex inops	Sun sedge	55.7	42.0	0.0	0.0
Dalea purpurea	Purple prairie clover	0.0	0.0	12.3	0.0
Dichanthelium oligosanthes	Scribner's rosette grass	44.4	0.0	0.0	0.0
Dichanthelium wilcoxianum	Fall rosette grass	63.8	0.0	0.0	0.0
Distichlis spicata	Inland saltgrass	0.0	0.0	27.3	0.0
Echinacea angustifolia	Black samson	11.0	21.4	6.9	0.0
Eriogonum flavum	Golden buckwheat	0.0	2.5	0.0	0.0
Helianthus pauciflorus	Stiff sunflower	15.7	0.0	124.8	0.0
Hesperostipa comata	Needle-and-thread	149.5	50.3	69.1	85.1
Heterotheca villosa	Hairy false goldenaster	45.8	0.0	0.0	0.0
Juniperus horizontalis	Creeping juniper	114.4	0.0	0.0	0.0
Koeleria macrantha	Prairie junegrass	13.3	0.0	19.4	7.8
Lygodesmia juncea	Rush skeletonplant	6.0	0.0	0.0	1.5
Muhlenbergia cuspidata	Plains muhly	0.0	0.0	50.6	37.5
Nassella viridula	Green needlegrass	0.0	2.7	58.1	0.0
Pascopyrum smithii	Western wheatgrass	0.0	378.1	117.0	128.5
Poa compressa	Canada bluegrass	45.7	0.0	0.0	0.0
Poa pratensis	Kentucky bluegrass	54.4	0.0	0.0	0.0
Polygala alba	White milkwort	0.0	42.4	5.9	11.8
Ratibida columnifera	Prairie coneflower	0.0	33.9	0.0	0.0
Rosa arkansana	Prairie rose	31.1	27.4	0.0	0.0
Schizachyrium scoparium	Little bluestem	365.9	359.0	304.9	86.6
Sphaeralcea coccinea	Sphaeralcea coccinea	0.0	2.4	0.4	14.6
Symphyotrichum laeve	Smooth blue aster	10.6	0.0	11.8	0.0
Symphoricarpos occidentalis	Western snowberry	30.1	0.0	0.0	0.0

APPENDIX D

Loamy Ecological site species list by scientific name and kg/ha for each transect in the Grand River National Grasslands.

Scientific Name	**Common Name**	LM-1	LM-2	LM-3	LM-4
Achillea millefolium	Western yarrow	1.8	2.2	6.2	27.8
Agropyron cristatum	Crested wheatgrass	0.0	0.0	113.8	0.0
Antennaria neglecta	Field pussytoes	0.0	0.0	0.0	4.4
Artemisia dracunculus	Tarragon	0.0	0.0	0.0	39.0
Arabis suffrutescens	Woody rockcress	0.0	0.0	37.0	0.0
Artemisia ludoviciana	White sagebrush	0.0	13.4	0.0	117.1
Symphyotrichum falcatum	White prairie aster	0.0	0.0	0.0	20.4
Bouteloua gracilis	Blue gramma	75.8	142.6	228.4	167.0
Bouteloua dactyloides	Buffalograss	0.0	105.6	0.0	0.0
Carex duriuscula	needleleaf sedge	0.0	3.7	0.0	0.0
Carex filifolia	Threadleaf sedge	2.2	39.0	0.0	211.1
Carex inops	Sun sedge	0.0	1.9	0.0	0.0
Comandra umbellata	Bastard toadflax	0.0	1.5	0.0	0.0
Echinacea angustifolia	Black samson	0.0	6.2	0.0	0.0
Gaura coccinea	Scarlet beeblossom	0.0	0.0	0.0	2.3
Hesperostipa comata	Needle-and-thread	39.1	41.0	7.0	56.6
Koeleria macrantha	Prairie junegrass	31.3	24.8	0.0	8.3
Lactuca tatarica	Blue lettuce	0.0	0.0	0.0	4.2
Lygodesmia juncea	Rush skeletonplant	0.0	0.0	0.0	12.3
Melilotus officinalis	Yellow sweetclover	0.0	3.1	0.0	0.0
Nassella viridula	Green needlegrass	277.6	82.2	244.2	49.3
Pascopyrum smithii	Western wheatgrass	259.6	164.8	115.9	120.6
Pediomelum argophyllum	Indian breadroot	0.0	3.9	0.0	15.8
Phlox hoodii	Hoods phlox	0.0	0.0	0.0	9.7
Poa compressa	Canada bluegrass	77.7	0.0	347.3	0.0
Poa pratensis	Kentucky bluegrass	0.0	0.0	0.0	250.2
Ratibida columnifera	Prairie coneflower	0.0	1.1	0.0	4.3
Schizachyrium scoparium	Little bluestem	0.0	0.0	0.0	104.7
Sphaeralcea coccinea	Scarlet globemallow	8.0	0.0	2.6	0.0
Unknown grass	Unknown grass	7.7	0.0	0.0	0.0
Vicia americana	American vetch	0.0	0.6	0.0	0.0

Scientific Name	**Common Name**	LM-5	LM-6	LM-7	LM-8
Achillea millefolium	Western yarrow	23.4	18.7	10.9	7.0
Agropyron cristatum	Crested wheatgrass	0.0	0.0	56.3	0.0
Antennaria neglecta	Field pussytoes	4.1	0.0	0.0	0.0
Aristida purpurea	Purple threeawn	87.4	0.0	0.0	31.9
Arabis suffrutescens	Woody rockcress	24.5	0.0	0.0	0.0
Artemisia frigida	Prairie sagewort	21.0	32.8	0.0	0.0
Artemisia ludoviciana	White sagebrush	10.6	0.0	0.0	0.0
Astragalus laxmannii	Prairie milkvetch	17.1	0.0	0.0	0.0
Bouteloua gracilis	Blue gramma	287.0	134.8	212.9	91.9
Bromus arvensis	Field brome	1.5	0.0	0.0	0.0
Bouteloua dactyloides	Buffalograss	0.0	0.0	83.1	0.0
Calamagrostis montanensis	Plains reedgrass	0.0	1.1	0.0	0.0
Carex duriuscula	needleleaf sedge	0.0	0.0	0.0	37.8
Carex filifolia	Threadleaf sedge	51.7	118.1	0.0	0.0
Echinacea angustifolia	Black samson	0.0	20.2	0.0	5.7
Machaeranthera pinnatifida	Lacy tansyaster	14.3	0.0	0.0	0.0
Hesperostipa comata	Needle-and-thread	34.1	18.9	60.9	24.2
Hesperostipa spartea	Porcupine grass	11.8	0.0	0.0	5.5
Koeleria macrantha	Prairie junegrass	17.0	0.0	21.3	18.3
Liatris punctata	Dotted blazing star	0.0	0.0	0.0	3.6
Lygodesmia juncea	Rush skeletonplant	14.7	0.0	0.0	0.0
Nassella viridula	Green needlegrass	125.2	70.8	104.3	81.4
Pascopyrum smithii	Western wheatgrass	238.5	246.6	681.8	293.9
Pediomelum argophyllum	Indian breadroot	2.2	0.0	0.0	0.0
Phlox hoodii	Hoods phlox	0.0	0.2	0.0	0.0
Poa compressa	Canada bluegrass	0.0	0.0	0.0	88.7
Ratibida columnifera	Prairie coneflower	110.6	55.1	0.0	0.0
Rosa arkansana	Prairie rose	0.0	0.0	0.0	11.2
Sphaeralcea coccinea	Scarlet globemallow	0.0	7.1	21.0	9.9
Symphyotrichum ericoides	White heath aster	0.0	0.0	0.0	13.4
Symphyotrichum falcatum	White prairie aster	0.0	4.7	0.0	0.0
Taraxacum officinale	Common dandelion	0.0	2.1	0.0	0.0
Tragopogon dubius	Goatsbeard	0.0	0.8	0.0	0.0

APPENDIX E

Claypan Ecological site species list by scientific name and kg/ha for each transect in the Grand River National Grasslands.

Scientific Name	**Common Name**	CP-1	CP-2	CP-3	CP-4
Achillea millefolium	Western yarrow	0	2.4	15.3	2.2
Artemisia frigida	Prairie sagewort	29.5	0	0	0.3
Artemisia ludoviciana	White sagebrush	0	7.1	0	0
Bouteloua curtipendula	Sideoats grama	0	35	0	0
Bouteloua gracilis	Blue gramma	47.8	34.9	166.1	73.5
Calamovilfa longifolia	Prairie sandreed	0	0	0	16.5
Calamagrostis montanensis	Plains reedgrass	0	1.01	0	0
Carex filifolia	Threadleaf sedge	42.2	46.1	12	3.5
Comandra umbellata	Bastard toadflax	0	70.7	0	0
Distichlis spicata	Inland saltgrass	0	0	0	0
Dodecatheon pulchellum	Darkthroat shootingstar	2.1	0	0	0
Echinacea angustifolia	Black samson	0	0.6	0	0
Glycyrrhiza lepidota	American licorice	0	14.6	0	0
Koeleria macrantha	Prairie junegrass	1.4	0	0	1.18
Nassella viridula	Green needlegrass	12.2	134	43	0
Pascopyrum smithii	Western wheatgrass	92.7	99.6	255.1	279
Pediomelum argophyllum	Indian breadroot	0	0	0	0.6
Phlox hoodii	Hoods phlox	0	0	7.4	0
Poa compressa	Canada bluegrass	38.3	0	0	0
Poa pratensis	Kentucky bluegrass	591	405	211.1	280
Ratibida columnifera	Prairie coneflower	0	0	0	31.4
Sphaeralcea coccinea	Scarlet globemallow	0	0	0	0.9
Symphyotrichum ericoides	White heath aster	0	14.1	0	0
Symphyotrichum falcatum	White prairie aster	0	2.7	0	0
Symphoricarpos occidentalis	Western snowberry	0	13.3	0	57.1
Tragopogon dubius	Goatsbeard	0	0.5	0	0

Scientific Name	**Common Name**	CP-5	CP-6	CP-7	CP-8
Achillea millefolium	Western yarrow	1.7	0.0	4.8	0.0
Antennaria neglecta	Field pussytoes	0.0	0.0	23.2	0.0
Artemisia ludoviciana	White sagebrush	0.0	0.0	0.0	26.5
Bouteloua curtipendula	Sideoats grama	0.0	0.0	0.0	57.8
Bouteloua gracilis	Blue gramma	151.8	51.2	259.6	279.6
Bromus arvensis	Field brome	0.0	3.6	0.0	0.0
Bouteloua dactyloides	Buffalograss	13.4	0.0	0.0	0.0
Calamovilfa longifolia	Prairie sandreed	0.0	0.0	17.9	0.0
Calamagrostis montanensis	Plains reedgrass	0.0	0.0	0.0	4.5
Carex filifolia	Threadleaf sedge	39.1	0.0	62.4	77.6
Comandra umbellata	Bastard toadflax	0.0	0.0	0.0	4.8
Distichlis spicata	Inland saltgrass	0.0	0.0	142.1	0.0
Echinacea angustifolia	Black samson	0.0	0.0	0.0	3.0
Gutierrezia sarothrae	Broom snakeweed	7.6	0.0	0.0	7.4
Hesperostipa comata	Needle-and-thread	0.9	0.0	23.1	0.6
Koeleria macrantha	Prairie junegrass	2.2	23.9	0.2	16.7
Nassella viridula	Green needlegrass	165.6	91.2	0.0	0.0
Opuntia polyacantha	Plains pricklypear	0.0	0.0	79.5	0.0
Oxytropis lambertii	Purple locoweed	0.0	0.0	0.0	1.8
Pascopyrum smithii	Western wheatgrass	140.4	219.6	164.7	142.9
Pediomelum argophyllum	Indian breadroot	0.0	0.0	0.7	0.0
Pediomelum esculentum	Large indian breadroot	0.0	0.0	0.0	1.8
Poa compressa	Canada bluegrass	5.8	0.0	46.1	0.0
Poa pratensis	Kentucky bluegrass	187.3	439.5	16.7	160.7
Poa secunda	Sandberg's bluegrass	0.0	7.3	0.0	0.0
Ratibida columnifera	Prairie coneflower	57.4	0.0	0.0	0.0
Sphaeralcea coccinea	Scarlet globemallow	7.3	3.0	0.0	2.8
Symphyotrichum ericoides	White heath aster	0.0	0.0	0.0	12.2

APPENDIX F

Thin Loamy Ecological site species list by scientific name and kg/ha for each transect in the Grand River National Grasslands.

Scientific Name	**Common Name**	TL-1	TL-2	TL-3	TL-4
Ambrosia psilostachya	Cuman ragweed	0.0	0.0	0.0	3.5
Aristida purpurea	Purple threeawn	0.0	11.8	50.0	14.0
Artemisia dracunculus	Tarragon	0.0	0.0	4.5	0.0
Artemisia frigida	Prairie sagewort	0.0	0.0	0.0	15.2
Artemisia ludoviciana	White sagebrush	0.0	0.0	0.0	21.1
Symphyotrichum falcatum	White prairie aster	0.0	27.3	0.0	0.0
Bouteloua curtipendula	Sideoats grama	0.0	74.8	0.0	0.0
Bouteloua gracilis	Blue gramma	143.0	35.3	108.5	27.8
Bromus arvensis	Field brome	0.0	0.0	0.0	7.5
Calamovilfa longifolia	Prairie sandreed	0.0	34.4	0.0	0.0
Carex filifolia	Threadleaf sedge	271.1	161.4	122.8	122.4
Carex nebrascensis	Nebraska sedge	0.0	0.0	0.0	28.8
Comandra umbellata	Bastard toadflax	0.0	0.0	0.8	0.0
Dichanthelium oligosanthes	Scribner's rosette grass	0.0	0.0	0.0	29.8
Echinacea angustifolia	Black samson	0.0	0.6	6.7	0.0
Gaura coccinea	Scarlet beeblossom	0.0	0.0	0.0	1.8
Gutierrezia sarothrae	Broom snakeweed	0.0	0.0	3.9	0.0
Hairy gold aster	Hairy gold aster	0.0	0.0	0.0	0.0
Hesperostipa comata	Needle-and-thread	46.2	76.7	44.1	40.8
Koeleria macrantha	Prairie junegrass	0.0	21.3	21.1	4.2
Liatris punctata	Dotted blazing star	3.6	0.0	0.0	0.0
Lygodesmia juncea	Rush skeletonplant	0.0	1.6	0.0	0.0
Nassella viridula	Green needlegrass	0.0	0.0	0.0	81.4
Pascopyrum smithii	Western wheatgrass	50.3	5.0	93.9	224.5
Pediomelum argophyllum	Indian breadroot	0.0	0.5	1.4	0.0
Phlox hoodii	Hoods phlox	0.0	0.0	11.8	0.0
Poa compressa	Canada bluegrass	0.0	0.0	0.0	5.4
Poa pratensis	Kentucky bluegrass	0.0	0.0	4.0	155.6
Ratibida columnifera	Prairie coneflower	0.0	0.0	21.4	0.0
Rosa arkansana	Prairie rose	9.4	0.0	0.0	32.0
Schizachyrium scoparium	Little bluestem	0.0	354.2	0.0	0.0
Sphaeralcea coccinea	Scarlet globemallow	5.5	1.3	0.0	3.6
Symphoricarpos occidentalis	Western snowberry	0.0	0.0	0.0	123.1
Unkown Forb	Unkown Forb	0.0	0.0	0.0	3.8

Scentific Name	Common Name	TL-5	TL-6	TL-7	TL-8
Aristida purpurea	Purple threeawn	4.3	0.0	0.0	0.0
Artemisia dracunculus	Tarragon	0.0	0.0	6.1	0.0
Artemisia frigida	Prairie sagewort	0.0	0.0	2.2	6.9
Symphyotrichum falcatum	White prairie aster	0.0	4.1	0.0	0.0
Bouteloua gracilis	Blue gramma	138.9	35.6	54.8	3.5
Bromus tectorum	Cheatgrass	5.8	0.0	0.0	0.0
Calamovilfa longifolia	Prairie sandreed	0.0	8.7	0.0	0.0
Carex filifolia	Threadleaf sedge	461.9	297.1	285.5	565.4
Comandra umbellata	Bastard toadflax	0.0	0.0	12.8	0.0
Dalea purpurea	Purple prairie clover	0.0	0.0	0.9	0.0
Hairy gold aster	Hairy gold aster	0.0	0.0	11.8	0.0
Hesperostipa comata	Needle-and-thread	84.4	50.0	29.8	139.4
Koeleria macrantha	Prairie junegrass	0.6	6.2	0.0	0.0
Lactuca tatarica	Blue lettuce	0.0	6.7	0.0	2.7
Liatris punctata	Dotted blazing star	0.0	6.1	3.3	42.8
Lygodesmia juncea	Rush skeletonplant	4.9	7.6	8.0	57.0
Nassella viridula	Green needlegrass	0.0	17.5	0.0	0.0
Opuntia fragilis	Brittle pricklypear	0.0	0.0	0.0	28.1
Pascopyrum smithii	Western wheatgrass	135.7	98.8	202.0	45.2
Phlox hoodii	Hoods phlox	0.0	6.9	0.0	0.0
Poa pratensis	Kentucky bluegrass	0.0	0.6	2.2	0.0
Polygala alba	White milkwort	7.5	6.9	0.0	0.0
Ratibida columnifera	Prairie coneflower	0.0	192.5	0.0	0.0
Schizachyrium scoparium	Little bluestem	0.0	0.0	0.0	129.1
Sphaeralcea coccinea	Scarlet globemallow	0.7	0.0	6.3	0.0
Symphyotrichum ericoides	White heath aster	0.0	12.3	0.0	0.0
Symphoricarpos occidentalis	Western snowberry	0.0	2.2	0.0	0.0