BIOLOGICAL CAPABILITY OF SELECTED ECOLOGICAL SITES IN THE WESTERN DAKOTAS

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Biological Capability 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

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ABSTRACT

Sharp-tailed grouse habitat on the Dakota Prairie Grasslands are assessed by habitat structure with the use of the Robel pole to measure visual obstruction readings (VOR). The purpose of this study was to determine 1) if all selected ecological sites (loamy, thin loamy, and claypan) are biologically capable of producing high structure (VOR > 3.5 in) with 3 years of protection from livestock grazing and 2) if strong and consistent correlations exist between standing crop and visual obstruction among ecological sites and across years. Results showed that 1) all selected ecological sites were biologically capable of producing high structure, 2) strong correlations between standing crop and visual obstruction were not consistent among ecological sites and across years, 3) year effects were evident in plant community composition, and 4) 2,534 $kg \cdot ha^{-1}$ (se ± 205.3) of standing crop provides the mean threshold to determine if the selected ecological sites are biologically capable.

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INTRODUCTION

Sharp-tailed grouse (*Tympanuchus phasianellus*) are a valuable resource in North and South Dakota. Sustainable populations of sharp-tailed grouse hold value not only as their aesthetic contribution to native rangelands, but also to the states' economy and ecological function. Hunters travel for miles to fill bag limits, expecting to see the habitat in near-prime condition. In doing so, they support their local and state economies through purchasing hunting equipment, ammunition, and/or fuel for their vehicles. However, in order to maintain viable, healthy, and sustainable populations of these game birds, wildlife and land managers must make informed decisions about the management of this species and its associated seasonal habitats.

Making informed decisions regarding sharp-tailed grouse populations revolves around understanding their habitat needs. One factor concerning sharp-tailed grouse recruitment and survival is habitat structure. Structure is defined by the US Forest Service as the vertical characteristics of vegetation (USDA, Forest Service 2001), with height and density being of primary importance (Hamerstrom et al. 1957). Sharp-tailed grouse rely on various types of vegetation structures throughout the year, depending on seasonal needs. Short vegetative structure is required during the breeding season on lekking grounds, while tall structure is desired during the nesting and brood-rearing seasons to protect nests and chicks from predation and harsh weather conditions (Hanowski et al. 2000, Prose et al. 2002). A couple methods used to assess habitat include measuring annual production via vegetative clippings and visual obstructive readings (VOR) with a Robel pole.

Vegetative clipping is a commonly used method to estimate biomass production on range and pasturelands (Milner and Hughes 1968). However, this method is destructive, time-consuming, labor-intensive, and requires extensive personnel knowledge of plant species identification. Despite these drawbacks, clipping is a highly effective method to determine species composition and overall production across a selected landscape. The Robel method was developed by Robel et al. (1970) as a means to estimate standing crop on rangelands, assess structure of wildlife habitat (Robel et al. 1970), and monitor grazing practices (Volesky et al. 1999). However, VOR is limited by its inability to describe indicators of biologic integrity as well as ecological and hydrological functionality of the system (Gearhart 2011). Another downside of VOR as an indirect sampling method is that it is restricted to measuring only estimates of total aboveground biomass production and cannot distinguish between previous and current year’s growth (Volesky 1999). In addition, the Robel pole does not address management issues related to the proportion of standing crop that is actual forage, forage quality, forage palatability, and long-term changes in the vegetative community, such as trends in species composition (Uresk and Juntti 2008).

Analyzing height to weight relationships between clipped vegetation and VOR will help managers determine the effectiveness and reliability of VOR at predicting standing crop and aboveground biomass. If VOR is determined to be a reliable means to assess vegetation across years on the mixed grass prairie of North and South Dakota, land managers would be equipped with a quick and easy method to estimate standing crop. Currently, the USFS uses VOR as a method to assess whether management strategies are capable of providing the desired structural distribution on the landscape at the end of the grazing season on the Dakota Prairie Grasslands (DPG; Benkobi et al. 2000, USDA, Forest Service, 2001).

In order to manage sharp-tailed grouse populations, the USFS and public has set desired objectives for structure, species composition, and a plethora of other objectives as outlined in the Land and Resource Management Plan (USDA, Forest Service 2001) through the National

Environmental Policy Act (NEPA) of 1969 process (Bass et al. 2001). The Rolling Prairie Geographic Area of the Little Missouri National Grasslands has set a desired structure objective of ten to 20% of the landscape as low structure (mean VOR = 1 - 1.5 inches), 50 – 70% moderate structure (mean VOR = 1.5 – 3.5 inches), and 20 – 30% high structure (mean VOR > 3.5 inches; USDA Forest Service 2001). The USFS defines biologically capable as the maximum VOR (long-term biologic potential) for a particular site that occurs where the forage form the last one or two growing seasons has not been removed by livestock and where the current successional state of a site maximizes mid and tall grass species components and vigor (Sousa 1987, USDA, Forest Service, 1999). They assume a site is biologically capable if it can produce at least 1,232 $kg \cdot ha^{-1}$. Since most ecological sites are capable of producing at least 1,568 $kg \cdot ha^{-1}$, they assume most of the grasslands should be capable of producing high structure. Habitat types that are classified by the USFS as capable of producing high structure are western wheatgrass/green needlegrass, western wheatgrass/needle-and-thread grass, needle-and-thread/sedge, silver sage/western wheatgrass, big sage/western wheatgrass, and western snowberry (USDA, Forest Service 2001). Sites dominated by crested wheatgrass are also considered biologically capable of producing high structure (USDA, Forest Service 2001).

The objectives of this study were to 1) verify for the USFS and North Dakota and South Dakota Grazing Associations that all selected ecological sites are biologically capable of producing high structure and 2) determine if strong correlations between VOR and standing crop exist across study sites and years. We hypothesized that 1) all selected ecological sites are biologically capable of producing high structure (8.89 cm VOR) at the end of the grazing season when protected from livestock grazing 2) significant ($P \leq 0.05$) correlations and relationships ($R^2 \geq 0.60$) exist between standing crop and visual obstruction for each ecological site and year studied, 3) expectations developed by the USFS regarding the ability of ecological sites to produce high structure if standing crop is greater than 1,232 $kg \cdot ha^{-1}$ are true, and 4) plant community composition will not change as a result of three years of no grazing.

CHAPTER 1: LITERATURE REVIEW

Monitoring standing crop and structure

Monitoring aboveground plant material is important for managing grasslands. Accurate measurements of vegetative and habitat attributes, such as standing crop and structure, are important in making sound management decisions, including those regarding stocking rate and wildlife habitat. Some commonly used methods to measure standing crop include: dry-weight-rank (‘t Mannetje and Haydock 1963), weight-estimate (Pechanec and Pickford 1937), canopy height via measuring sticks (Harmoney et al. 1997), and plastic disks (Sharrow 1984). Structure can be assessed with a Nudds’ cover board (Nudds 1977) and both production and structure are commonly measured using a Robel pole (Robel et al. 1970).

The dry-weight-rank method was developed by ‘t Mannetje and Haydock (1963) as a means to quickly and accurately analyze the botanical composition of grasslands on a dry-weight basis without causing harm to the landscape. A quadrat is randomly placed in the pasture and an observer records all species present, estimating their rank in terms of first, second, and third on a dry-weight basis. This is repeated 50 to 100 times to give a data set for a pasture, and then the data are tabulated to provide the proportion of quadrats in which each species is ranked. Proportions are then multiplied by the factors of 70·19, 21·08, and 8·73 (where 70, 21, and 8 represent proportions of quadrats in which the species ranks first, second, and third; respectively, and 19, 08, and 73 represent the coefficients for the respective ranks; respectively; Ratcliff and Frost, 1990) and added to give the dry weight percent of the species. After comparing this method to results from hand-separated cut samples, no significant differences were detected. Thus, it was concluded that this sampling method can be used as an accurate method of botanical analysis, provided sufficient training has occurred for all observers (‘t Mannetje and Haydock 1963).

The weight-estimate method (Pechanec and Pickford 1937) utilizes features from the percentage-productivity (Stapledon 1912) and point-observation-plot methods (Stewart and Hutchings 1936). When using Pechanec and Pickford’s (1937) method, ocular estimates are made of plots situated in either a gridiron or patterned arrangement. Yield and floristic composition are measured in terms of green or dry weight of the current aerial phytomass growth. A high correlation (R^2 = 0.9197) between estimates and actual weights suggests this is a reliable method to determine actual phytomass production on individual plots.

Canopy height measurements via the canopy height stick method (Harmoney et al. 1997) have been used to determine forage availability in pastures with varying species composition. Canopy height is determined by vertically positioning a canopy height stick with 2 cm increments at level with the soil surface in the center of a sample frame area. Height is recorded to the nearest 2 cm based on the highest leaf tissue present. Although this method was determined very easy to use, it had a coefficient of determination of 0.55, with its accuracy being subject to forage type and species.

Plastic disks (Sharrow 1984) have been used to estimate phytomass production through height-weight relationships. This method measures sward canopy height and forage bulk via a meter stick inserted in the handle of a disc meter. Canopy height is measured by lowering the disc along the meter stick until the highest leaves touch the disc. Height is then read directly off the meter stick and forage bulk is measured by raising the disk until the top of the handle is flush with the end of the meter stick. Then it is released and the resting height is read directly from the meter stick. Coefficients of determination ranged from 0.70 to 0.90; however, erratic readings were given where soil surface micro-relief occurred.

Vegetative cover measurements consist of two major components: vertical and horizontal distributions of vegetation. The Nudds' coverboard (Nudds 1977) is a method that captures both the vertical and horizontal components and is effective in identifying variation in the vegetative structure of bird habitats. The board has dimensions of 2.5 m x 30.48 cm x 0.95 cm and is marked in vertical 0.5 m increments of alternating black and white strips. Through the utilization of aluminum spikes attached to the bottom corners of the board, it is able to stand upright in the ground. Vegetation is read at a distance of 15 m in a randomly chosen direction from a randomly selected point. The proportion of each 0.5 m interval covered by vegetation is recorded as a single digit "density score" that corresponds to the average value of a range of quintiles. Resulting data showed a decreasing F-value (33.51 to 1.26) with increasing seral stage age (*Elymus repens* (L.) Gould. fields to *Celtis occidentalis* L. –*Quercus rubra* L. forest), suggesting an increasingly uniform distribution of vegetation at all heights. Nudds concluded this method allows the analysis of temporal changes in vegetation structure within habitats.

History of the Robel pole

Visual obstruction measurements have been recorded with a Robel pole (Robel et al. 1970) for several decades to determine height and density of vegetation and to estimate standing crop. Developed by Robel et al. (1970), the Robel pole was first used as part of a long-term study on greater prairie chicken (*Tympanuchus cupido*) ecology in northeastern Kansas. This study made an attempt to correlate movements and locations of prairie chickens with habitat types. In order to accomplish this goal on the 2,500 ha grassland study area, a reliable method was needed to accurately describe habitat types. Species composition alone was not an adequate means of measurement since it could not evaluate grassland habitat potential for prairie chicken use. Hamerstrom et al. (1957) claimed height and density of grass was more important to prairie chickens and plant species composition within a landscape was not a critical factor to sustain prairie chicken populations. Since there had been few studies correlating the amount of vegetation present with various indices to visual obstruction, Robel et al. (1970) developed a method to quantify the visual obstruction technique of evaluating vegetative height and density, comparing vegetation weights to visual obstruction measurements made on the same plots.

The topography of the area where the Robel pole technique was first studied was characterized as homogenous vegetation on gently sloping, rounded hills separated by intermittent streams with major range sites classified as limestone breaks, shallow, and claypan. Thirty-20 m line transects were established in a north-south direction. The method was designed to measure the ability of grassland vegetation to obstruct vision, resembling another method described by Wight (1938) for forest understory. Robel used a round pole (3 x 150 cm) with alternating decimeters painted brown and white. The mid-point of each decimeter interval was marked with a narrow, black stripe, allowing the observer to distinguish between half-decimeters on the pole (Robel et al. 1970).

Visual obstruction measurements were made with the pole at mid-day from heights of 1.0, 0.8, and 0.5 m at distances of 4, 3, and 2 m; respectively, with the lowest visible half-decimeter or decimeter mark being recorded at each height and distance (Robel et al. 1970). After this step was performed at 2 m intervals and 10 cm west of the transect, vegetation was clipped to a height of 0.5 dm within a 20 x 50 cm rectangular plot along the transect tape directly in front of where the pole was situated. Vegetation was immediately dried for 48 hours at 60°C and weighed to 0.1 g. Following data collection, a multiple linear regression analysis was used to analyze the relationship between visual obstruction measurements and the weight of clipped vegetation from each plot.

After examining the raw data, Robel noticed a surprising relationship between visual obstruction (VO) measurements and the weight of vegetation clipped from each transect. A highly significant ($P < 0.01$) correlation coefficient ($R^2 = 0.9727$) was detected between the pooled means of each transect and the weight of vegetation collected from the respective transect. Since the collection of VO measurements from 90 points was extremely time consuming, further analyses needed to be conducted to determine if fewer observations would still provide significant relationships (Robel et al., 1970).

Upon comparing all variables (coded in order VO was taken in the field) with a simple correlation matrix, Robel concluded the VO measurement taken from a distance of 4 meters and a height of 1 meter provided the most reliable method in assessing the height and density of the vegetation. He also concluded VO measurements may prove to be a reliable method to determine standing crop of vegetation across habitat types (Robel et al. 1970).

VOR and standing crop correlations. The Robel pole method has experienced extensive, continued testing as a useful means to estimate total aboveground standing crop within the last two decades. Volesky et al. (1999) used the Robel pole to determine if VO could be used as an efficient double sampling method to estimate standing crop on upland range sites in the Nebraska Sandhills. A significant ($P < 0.01$) correlation between VO and standing crop existed. However, the relationship was poor, with an R^2 value of 0.31 in 1995 and 0.41 in 1996, where two readings were taken to develop an average mean for each sample site. Pooling observations from 12 sample sites into pasture means did not strengthen the relationship between VO and standing crop. As a result, they concluded VO was not useful as a double sampling technique for predicting total above-ground phytomass on upland range sites.

Benkobi et al. (2000) tested the correlation between VO and standing crop in the Nebraska Sandhills and found a strong linear relationship, where $R^2 = 0.88$. Their study also showed that predicting single values of standing crop would be more accurate with larger VORs versus small VORs. For example, for an estimate of 3,000 kg·ha^{-1}, the relative error would be about 10%, with an absolute error of 300. In contrast, an estimate of 600 kg·ha^{-1} would have a relative error of 50%, corresponding to an absolute error of 300. Thus, the relative error for standing crop increases for small VORs but the absolute error remains constant at 300 kg·ha^{-1} throughout the range of prediction.

In the tallgrass prairie near Stillwater, Oklahoma, regression models were developed for plot level (burned and unburned) and pasture level estimates (Vermeire and Gillen. 2001). Coefficients of determination based on burned and unburned plots were 0.64 and 0.79; respectively; however, coefficients of determination for pasture-level estimates had a coefficient of determination of 0.95, similar to the results from Robel et al. (1970). Models based on plots may have accounted for less variation because the true area measured by VO was unknown, three-dimensional, and probably varied between points, while quadrat size would have been two-dimensional and remained constant between points.

Until 2002, linear regression models had been limited to tallgrass prairie and sandhill vegetation range types. The primary objective of Vermeire et al. (2002) was to develop vegetation models to estimate standing crop across vegetation types: shortgrass plains and mixed prairie. They discovered a significant ($P < 0.01$) relationship where $R^2 \geq 0.89$ for both vegetation types. Although tallgrass (Vermeire and Gillen 2001) and shortgrass models were very similar, prediction model differences tended to occur among range types. The mixed grass prairie model differed from other habitats types, where two primary factors were considered responsible: plant morphology and management history. Additionally, they assessed that selecting the appropriate model for range types depends on objectives of the user and characteristics of the sites. In addition, VO models were expected to be more accurate and precise if they are developed for individual range types (Vermeire et al. 2002).

Several studies have been carried out within the Black Hills of South Dakota to test the relationship between VOR and phytomass. On the central Black Hills, Uresk and Benzon (2007) and Uresk et al. (2009) found significant ($P < 0.001$; $P \leq 0.01$) relationships between phytomass and VO within both the lower (0 – 5 bands; 0 – 3.6) and upper (> 5 bands; > 3.6 bands) regions of piecewise regression models. Uresk and Junttii (2008) also found a strong linear relationship between standing phytomass and VO on the Bighorn Nation Forest in Wyoming where $R^2 = 0.81$ ($P < 0.001$). Prediction of standing phytomass was excellent when sampling was confined to areas where the soil had been derived from sedimentary materials. On the northern Black Hills (Uresk et al. 2009b), a strong linear relationship existed ($P < 0.001$) where the coefficient of determination was 0.80. Uresk et al. (2010) found a significant ($P < 0.001$) correlation on the southern Bighorn National Forest on granitic soils within Idaho fescue (*Idahoensis festuca* Elmer) vegetation types ($R^2 = 0.75$). Uresk and Mergen (2012) found a strong linear relationship ($P = 0.001$) on the Buffalo Gap and Ogalala National Grasslands in South Dakota and Nebraska where $R^2 = 0.80$. Uresk (2012a) also evaluated the relationship between standing crop and VO on combined shallow clay, loamy overflow, and clayey ecological sites. He found significant ($P < 0.001$) correlations for both ecological sites where the combined shallow clay and loamy overflow ecological sites had an $R^2 = 0.79$, and clayey ecological sites had an $R^2 = 0.82$. Finally, Uresk (2012b) found a strong linear relationship on the sands and choppy sands ecological vegetation types in the Nebraska Sandhills, where $R^2 = 0.60$ ($\underline{P} < 0.001$).

Using the Robel pole to characterize vegetation structure on sharp-tailed grouse habitat

Landscape VORs. Although the different subspecies of sharp-tailed grouse inhabit grasslands with various amounts of woody vegetation (Aldrich 1963), they are all strongly dependent on vegetative structure for habitat selection (Hamerstrom et al 1957). Good quality grass and woody vegetation cover is also critical for sharp-tailed grouse habitat (Hillman and Jackson 1973). Native grasslands, in combination with cropland areas, are capable of providing cover required for nesting, brood-rearing, loafing, roosting, and escape (Brown 1961). An important aspect of habitat cover for sharp-tailed grouse is the height and density of vegetation and considered more important in sharp-tailed grouse habitat quality than plant species composition (Hamserstrom et al. 1957).

Land and wildlife managers characterize sharp-tailed grouse nesting and brood-rearing habitat through the quality of residual vegetation by utilizing the Robel pole (Robel et al. 1970, Prose et al. 2002). Habitat assessments are often done through a landscape approach, where an average VOR measurement is calculated from a number of transects and used to represent the habitat (Prose 1987). For example, Prose (1987) developed a model of residual vegetation where a landscape represented optimal nesting and brood-rearing conditions (VO ≥ 2 dm). He also used the model to describe the habitat suitability of the landscape. Nest and brood cover suitability was a function of the height and density of residual vegetation in the spring, relative area of nest and brood cover types, and the interspersion of the nest and brood cover types.

Spatial scale can also be used in determining VO on sharp-tailed grouse habitat; however, its influence on sharp-tailed grouse habitat use is poorly understood. Hens primarily select nesting habitat characterized by taller residual vegetation than found at random sites when compared at all scales (VO greater than or equal to 4 cm; Prose et al. 2002). Selection of shrub habitat was only evident at the 16 ha scale and patches of tall cover were greater at nest sites than random sites at both the 8 ha and 16 ha scales. However, the influences of patch size and overall percent area of cover classes on nesting habitat selection could not be separated (Prose et al. 2002).

Nest-site VORs. Higher reproductive potential has been associated with a relatively higher proportion of areas in grassland cover types (Prose 1987). Spring herbaceous residual cover is critical to nest survival since little new growth is adequately available when sharp-tailed grouse begin nesting. It also provides the majority of the nesting cover during drought years. Nest sites can be described in relatively precise detail by locating individual nest sites, measuring VO at each nest site, and then comparing the values to random sites on the study area. Sharp-tailed grouse on the Nebraska Sandhills selected nest sites with more tall (greater than or equal to 4 cm VOR) residual cover than random sites at all scales (Prose et al. 2002). In addition, Kohn (1976) found 40 of 43 nest sites had an average VOR greater than 15 cm.

Although livestock grazing reduces residual vegetation pertinent to nesting cover, it is commonly cited in reducing sharp-tailed grouse abundance and distribution (Hillman and Jackson 1973). Evidence has shown that rotation grazing systems may sustain necessary cover for sharp-tailed grouse nesting. Kirby and Grosz (1995) utilized a short duration and twice-over grazing rotation system on the Central Grasslands Research Center in North Dakota. They found 88% of nest site VORs were greater than 10.2 cm. Average nest site VOR for grazed pastures was 19.3 cm and 18.3 cm for nongrazed pastures. VORs at successful sites and unsuccessful sites in grazed (20.3 vs 17.3) and nongrazed pastures (15.2 vs 18.3) did not differ.

Sedivec (1994) also compared nest sites in grazed and nongrazed rangelands. He found average nest site VOR on grazed rangelands was 18.2 cm, lower ($P \le 0.05$) than 21.2 cm nest site VOR on nongrazed rangeland. The average VOR for all grouse found was 18.8 cm; however, sharp-tailed grouse showed higher use of taller vegetative cover, supporting previous results from Kirsch et al. (1973) and Grosz (1988). He also found nest density was higher ($P \le 0.05$) on nongrazed rangeland (1.2 nests/40.5 ha) than grazed rangeland (0.6 nests/40.5 ha). In contrast, nesting success was lower ($P \le 0.05$) on nongrazed rangeland (6.2%) than grazed rangeland (18.9%). Hatched and depredated nest sites were found in areas showing no difference ($P > 0.05$) in average VORs: hatched sites had an average VOR of 18.7 cm while depredated nest sites had an average VOR of 18.6 cm (Sedivec 1994).

US Forest Service Guidelines and Protocols

Along with the greater prairie chicken (*Tympanuchus cupido* pinnatus), Greater sage-grouse (*Centrocercus urophasianus*), and black-tailed prairie dog (*Cynomys ludovicianus*), sharp-tailed grouse are considered a management indicator species (MIS) by the USDA Forest Service for high structure grasslands. As such, the USFS has developed guidelines to manage for the sustainability of sharp-tailed grouse populations. High vegetative structure is desired in areas where it would support nesting habitat quality. These areas should be characterized by moderate to highly productive soils and range sites, plant composition dominated by mid and/or tall grasses, and in close proximity to leks, shrub habitats, croplands, and other foraging habitats. USFS management strategies must also maintain high plant species diversity, including forbs, for brood-rearing habitat. Winter habitat should be enhanced by shrub patches and shrub components in woody draws and riparian areas (USDA, Forest Service 2001).

The DPG is separated into four different Geographic Areas (Grand/Cedar, Badlands, Rolling Prairie, and Sheyenne) and describe management guidelines specific to the entire region. For example, desired seral and structural conditions have been tailored to their relative vegetation types, climate, and production. Within each geographic area, the USFS has outlined vegetative management objectives concerning MIS habitat needs, focusing on vegetative composition, seral stages, and desired structural objectives (USDA, Forest Service 2001).

Within the Grand/Cedar and Badlands Geographic Areas, the Forest Service aims to maintain a diversity of healthy mixed and short grass plant communities, where a full-spectrum of warm- and cool-season species are represented. Vegetation communities should be comprised of a mix of seral conditions with disturbance processes contributing to a “shifting mosaic” of vegetation structure and composition. In addition, guidelines were developed to support MIS populations. Early seral stage should comprise 10-15% of the landscape, mid seral 65-75% of the landscape, and 15-20% of the landscape for late seral stage. Low structure (1-1.5 in VO) should comprise 10-20% of the landscape, moderate structure (1.5-3.5 in VO) 50-70% of the landscape, and high structure (> 3.5 in VO) 20-30% of the landscape (USDA, Forest Service, 2001).

Sharp-tailed grouse selection of low structured habitat

Population dynamics of sharp-tailed grouse and other MIS provide insight to the integrity of the larger ecological system to which they belong (Geaumont et al. 2010). Therefore, their behavior and population dynamics must be well understood for effective rangeland management. This includes understanding how predation and habitat structure influence habitat selection, sensitivity changes in habitat structure, and how these changes effect population demographics, such as nesting success.

Habitat structure is a principal feature of the landscape driving sharp-tailed grouse habitat selection (Hamerstrom et al. 1957). Optimal sites provide overhead and lateral cover to protect and conceal them year-round from avian and mammalian predators (Goddard et al. 2009). If a selected site does not provide adequate protection, sharp-tailed grouse will have no means of concealment, predation rates will increase, nest success will decline, chicks will be depredated on, and recruitment rates will eventually decrease, resulting in a non-sustainable population (Goddard and Dawson 2009).

Just as habitat structure influences habitat selection of sharp-tailed grouse, it also influences their behavior and population dynamics. Population dynamics, such as production and recruitment, are critical as they shape population trends. Sharp-tailed grouse production is influenced by the percentage of nesting hens, number of eggs per nest, nest success, and recruitment (survival of juveniles to reproductive age; Flanders-Wanner et al. 2004). During the breeding season, sharp-tailed grouse utilize sparsely vegetated areas with low vegetative structure. These areas are referred to as leks, where male sharp-tailed grouse perform their mating dance (Hanowski et al. 2000). When nesting, hens prefer nest sites composed of tall residual cover (Prose et al. 2002, Sedivec 1994, Kohn 1976) within 2.5 km of the breeding grounds (Giesen 1997). Habitat selection during the brood-rearing season is limited by the presence of adequate forage and thermal cover to aid in thermoregulation for chicks (Klott and Lindzey 1990; Goddard et al. 2009).

In addition to their specific habitat requirements, sharp-tailed grouse movements are also sensitive to changes in habitat structure. Active sites within 3 km of leks may be abandoned when there are minute changes to cover types in their home range (Hanowski et al. 2000). However, such drastic sensitivity may be characteristic of certain areas within their range of distribution. As a result of changes in habitat structure, population dynamics of sharp-tailed grouse will be affected, including reproductive, nesting success, and recruitment. These demographics are affected by weather, habitat conditions, predation, availability of insects for chick diets, and disturbance (Flanders-Wanner et al. 2004; Goddard and Dawson 2009).

Weather affects survivability of sharp-tailed grouse in several different ways. It plays a large role in the productivity of the landscape, availability of thermal and security cover, and affects nest initiation, clutch size, and length of brood-rearing (Neave and Wright 1969; Boggs et al. 1977). Habitat conditions affect the ability of grouse to hide from predators and protect themselves from harsh weather conditions. If inadequate habitat conditions exist, predators may find grouse easier, resulting in increased mortality rates. Weather also influences the availability of insects, which is imperative for chick survival during the first week of life (Goddard and Dawson 2009).

Spring height and density measurements of residual cover from previous growing seasons are primary features of sharp-tailed grouse habitat to predict the quality of nesting cover (Kohn 1976). Residual cover is critical because little new growth is available early in the spring during nest initiation and can provide much of the cover necessary to conceal nests from predators. However, residual cover is usually the most limiting factor for sharp-tailed grouse (Kessler and Bosch 1982). Quantitative standards regarding habitat structure have been established by the USDA Forest Service. These standards are intended to ensure that habitat remains suitable for sharp-tailed grouse under various land uses, including grazing. However, structure varies between ecological sites due to differences in soil characteristics, changes in local climate and weather conditions, and plant community types (Prose et al. 2002).

As mentioned earlier, habitat structure drives habitat selection of sharp-tailed grouse (Hamerstrom et al. 1957). When nesting, they select the most suitable habitat available and prefer areas of high structure (visual obstruction greater than 4 cm) within a mosaic of low and high structure. In other words, they prefer areas of tall, dense residual cover, suggesting this is a major component of nesting habitat (Prose et al. 2002). However, tall residual cover is not always available as it varies with climate, soil type, plant community, and disturbances such as grazing (Flanders-Wanner et al. 2004). While the availability of adequate nesting habitat varies, several other factors can affect a hen's decision regarding nest placement.

Predation theories. To better understand the role low habitat structure plays on nesting habitat selection of sharp-tailed grouse, behavioral mechanisms influencing habitat selection and reaction to predators must be understood. Habitat selection is generally a function of predation risk; however, several factors other than habitat structure and nest cover affect predation events. These include population and/or nest density, predator type, predator density, predation patterns, and proximity of nests to a predator's home range (Niemuth and Boyce 1995). As a result, the predation risk theory (which refers to the perceived risk of predations) (Reichert and Hedrick 1990), ghost of predation past hypothesis (which relates to anti-predator behavior) (Byers 1998), and other hypotheses have been developed in an attempt to understand how prey respond to predators (Storch 2013).

Sharp-tailed grouse must first be able to recognize the presence of predators on the landscape to show a preference regarding habitat selection. Predator recognition stems from heritable predisposition or a history of predation experiences (Riechert and Hedrick 1990, Magurran 1990, Brown et al. 1997). In addition, predator presence alone does not force prey to seek refuge. There must also be a perceived risk. The coupling of predator recognition and perceived risk appear to result in anti-predator behavior of a prey species (Storch 2013) such as sharp-tailed grouse.

Predation patterns on sharp-tailed grouse may be density-dependent, where predation intensity is a factor of prey-density. Some studies show predation intensity is greatest at high nest density sites; however, nest-associated predation may be influenced by factors varying from year to year, such as predator community composition and vegetative cover. Density-dependent predation may be more likely to occur if the total number of nests at a site is sufficient for predators to encounter nests (Niemuth and Boyce 1995). However, predation is not always dependent on density alone and specific conditions may be required for density-dependent predation to occur (Reitsma 1992). For example, if nests are clustered, despite high-density, predation may be low as clustering could make it more difficult for a predator to locate a nest (Niemuth and Boyce 1995).

Geomorphic isolation also affects anti-predator behavior. The “ghost of predation past hypothesis” suggests a prey species will retain anti-predator behavior after isolation from a predator until it is too costly to do so (Byers 1998). Based on this hypothesis, if a sharp-tailed grouse population has not been exposed to a mammalian predator, it may still retain the heritable predisposition to hide from predators in tall herbaceous cover. However, if this behavior becomes too costly, it may begin to show no preference for tall structured habitat and may nest in low structured habitats instead.

Nest predation association with leks. Nest predation may be associated with displaying males on leks since the majority of nests are located near these sites. The “sentinel/decoy model” suggests there is a zone around a lek that is subject to decreased predator density and male lek display may reduce nest predation. Displaying males may act as a decoy, luring predators away from nests, and serving as a sentinel by alerting females when a predator is approaching (Phillips 1990). In contrast, the “male avoidance model” suggests females may select males displaying further from nest sites in order to avoid costs associated with the presence of males (Wrangham 1980) as they may increase nest conspicuousness, despite potentially serving as a decoy. This model predicts that nesting success should increase with distance from male display sites (Phillips 1990).

The “sentinel/decoy model” may play a larger role than the “male avoidance model” in reducing nest predation. Nest success does not always appear to be a function of distance from leks; however, most nests tend to be located within an audible range of displaying males. Evidence also shows hens may select and prefer nest sites at an optimal distance from leks, supporting the “sentinel/decoy model” (Phillips 1990).

Predators and avoidance. Factors influencing sharp-tailed grouse behavior undoubtedly affect nest location and thus nest habitat selection; however the types of predators to which they are exposed also influence habitat selection. Sharp-tailed grouse are exposed to two main types of predators: visual predators and olfactory predators. Visual predators, mainly raptorial birds, rely on line-of-sight to capture their prey and hunt primarily during the day when light levels enhance their visual acuity. Mammalian predators, such as skunks, feral hogs, and badgers, may be either visual or olfactory, relying on smell to locate their prey when environmental conditions favor its use (Green and Anthony 1989; Mills 1990; and Nams 1997; Conover and Borgo 2014). Although they may use either modality, they generally rely on one or the other to capture their prey (Wells and Lehner 1978).

Since these predators use different techniques to locate their prey, various parts of the landscape are better suited to provide protective cover. Visual obstructions, such as plants, are best suited for concealing sharp-tailed grouse from visual predators. However, they offer poor protection from olfactory predators as scents move around obstacles. According to the olfactory concealment theory, prey must hide their odor plume (the volume of air downwind of an odor source that is at a sufficient concentration to be detected by a predator) by concealing themselves in areas where airflow is turbulent and high wind velocities and updrafts occur, such as south-facing slopes, making it less likely for predators to detect their scent (Conover 2007). Results have shown that, when visual obstruction does not differ between nest sites and the rest of the landscape, sharp-tailed grouse select sites that are more difficult to be located by olfactory predators (Conover and Borgo 2009). However, Conover and Borgo (2009) may have conducted this study in an area mostly subjected to olfactory predators, causing sharp-tailed grouse to potentially find it more feasible to select sites with greater updrafts than sites that would be more capable of protecting them from visual predators.

First versus re-nest attempts. Despite evidence that hens generally prefer tall, dense structure, habitat selection may differ between first- and re-nest attempts (hens will re-nest if the first nest attempt failed; Goddard et al. 2009). The extent to which shrub-cover dominates nest habitat is greatest during first-nest attempts, and is less important during re-nesting (Goddard and Dawson 2009). Selection of agricultural areas (disturbed by cropland and pastureland) and shrub-steppe habitat also may differ between first- and re-nest attempts. During first nest attempts, hens appear to prefer shrub-steppe habitat to agricultural areas. However, preference may lessen during re-nesting as there seems to be little to no difference in habitat selection between agricultural areas and shrub-steppe habitat (Goddard et al 2009). This change in habitat characteristics may be related to seasonal distribution and availability of cover and habitats (Goddard and Dawson 2009).

Nesting in grazed areas. Livestock decrease areas of tall, dense vegetation needed by sharp-tailed grouse for security cover from predators through grazing and trampling activities, and commonly blamed for reducing sharp-tailed grouse abundance and distribution (Hillman and Jackson 1973) since they contribute to a decline in nest initiation in grazed pastures (Kirsch et al 1973; Kohn 1976; Sedivec 1994). Sedivec (1994) reported greater nest density on nongrazed rangeland (1.2 nests/40.5 ha) versus grazed rangeland (0.6 nests/40.5 ha) in North Dakota; however, the number of successful nests was greater in grazed rangeland (18.9%) than nongrazed rangeland (6.2%). These results also supported Kirby and Grosz (1995) and may be attributed to the subsequent presence of predators at either site.

Grazed sites are areas of human and livestock activity, making them potentially unattractive habitat sites for some mammalian predators due to reduced levels of cover. Conversely, nongrazed areas may attract more predators as they would be able to provide more cover (Kirby and Grosz 1995). This deterrence of predators from grazed areas may, over time, support the “ghost of predation past hypothesis” through the isolation of sharp-tailed grouse from predators (Byers 1998).

CHAPTER 2: BIOLOGICAL CAPABILITY OF SELECTED ECOLOGICAL SITES IN THE WESTERN DAKOTAS

Abstract

Sharp-tailed grouse habitat on the Dakota Prairie Grasslands are assessed by habitat structure with the use of the Robel pole to measure visual obstructive readings (VOR). The purpose of this study was to determine 1) if all selected ecological sites (loamy, thin loamy, and claypan) are biologically capable of producing high structure (VOR > 3.5 in) with 3 years of protection from livestock grazing and 2) if strong and consistent correlations exist between standing crop and visual obstruction among ecological sites and across years. Results showed that 1) all selected ecological sites were biologically capable of producing high structure 2) strong correlations between standing crop and visual obstruction were not consistent among ecological sites and across years, 3) year effects were evident in plant community composition, and 4) 2,534 $kg \cdot ha^{-1}$ (se ± 205.3) of standing crop provides the mean threshold to determine if the selected ecological sites are biologically capable.

Introduction

Sharp-tailed grouse (*Tympanuchus phasianellus*) are a valuable resource to North and South Dakota. Sustainable populations of sharp-tailed grouse hold value not only as their aesthetic contribution to native rangelands, but also to the states’ economy and ecological function. Hunters travel for miles to fill bag limits, expecting to see the habitat in near-prime condition. In doing so, they support their local and state economies through purchasing hunting equipment, ammunition, and/or fuel for their vehicles. However, in order to maintain viable, healthy, and sustainable populations of these game birds, wildlife and land managers must make informed decisions about the management of this species and its associated seasonal habitats.

Making informed decisions regarding sharp-tailed grouse populations revolves around a better understanding of their habitat needs. One factor concerning sharp-tailed grouse recruitment and survival is habitat structure. (Goddard and Dawson, 2009) Structure is defined by the US Forest Service as the vertical characteristics of vegetation (USDA, Forest Service 2001), with height and density being of primary importance (Hamerstrom et al. 1957). Sharp-tailed grouse rely on various types of vegetation structures throughout the year, depending on their seasonal needs. Short vegetative structure is required during the breeding season on lekking grounds, while tall structure is needed during the nesting and brood-rearing seasons to protect nests and chicks from predation and harsh weather conditions (Hanowski et al. 2000, Prose et al. 2002). A couple methods used to assess habitat include measuring annual production via vegetative clippings and visual obstruction readings (VOR) with a Robel pole.

Vegetative clipping is a commonly used method to estimate biomass production on range and pasturelands (Milner and Hughes 1968). However, this method is destructive, time-consuming, labor-intensive, and requires extensive personal knowledge of plant species identification. Despite these drawbacks, clipping is a highly effective method to determine species composition and overall production across a selected landscape. The Robel pole method was developed by Robel et al. (1970) as a means to estimate standing crop on rangelands and has been used to assess structure of wildlife habitat (Robel et al. 1970) and monitor grazing practices (Volesky et al. 1999). However, VOR is limited by its inability to describe indicators of biologic integrity as well as ecological and hydrological functionality of the system (Gearhart 2011). Another downside of VOR as an indirect sampling method is it’s restriction at measuring only estimates of total aboveground standing crop, and cannot distinguish between previous and current year’s growth (Volesky 1999). In addition, the current Robel pole design does not address management issues related to the proportion of standing crop that is forage, forage quality, forage palatability, and long-term changes in the vegetative community, such as trends in species composition (Uresk and Juntti 2008).

Analyzing height to weight relationships between clipped vegetation and VOR will help managers determine the effectiveness and reliability of VOR at predicting standing crop and aboveground biomass. If VOR is determined to be a reliable tool to assess vegetation across years on the mixed grass prairie of North and South Dakota, land managers would be equipped with a quick and easy method to estimate standing crop. Currently, the USFS uses VOR as a method to assess whether management strategies are capable of providing the desired structural distribution on the landscape at the end of the grazing season on the Dakota Prairie Grasslands (DPG; Benkobi et al. 2000).

The USFS has set desired objectives regarding the type of structure they want to achieve across the landscape to better manage sharp-tailed grouse populations. Ten to 20% of the landscape should be characterized as low structure (0 - 1.5 inches), 50 – 70% moderate structure (1.5 – 3.5 inches), and 20 – 30% high structure (> 3.5 inches) (USDA Forest Service 2001). The USFS defines biologically capable as any site classified as grasslands dominated by mid- and/or tall grasses. Their assumption is a site is biologically capable of producing high structure if it can produce at least 1,232 $kg \cdot ha^{-1}$, with most sites capable of producing at least 1,568 $kg \cdot ha^{-1}$. Habitat types that are classified by the USFS as capable of producing high structure include western wheatgrass/green needlegrass, western wheatgrass/needle-and-thread grass, needle-and-thread/sedge, silver sage/western wheatgrass, big sage/western wheatgrass, and western snowberry. Sites dominated by crested wheatgrass are also considered biologically capable of producing high structure (USDA, Forest Service, 2001). Ecological site descriptions (ESDs) are also used by the USFS to manage rangelands. Ecological sites are defined as distinct types of land based on soil, landform, geological, and climate characteristics that differs from other kinds of land in its ability to produce specific kinds and amounts of vegetation and its ability to respond similarly to disturbances and management actions. State-and-transition models are described in ESDs and explain disturbances and management actions that cause shifts in vegetative community phases. These tools are implemented to develop management interpretations and to help assess the health of rangelands. (USDA, NRCS 2013)

The objectives of this study were to 1) verify for the USFS and North Dakota and South Dakota Grazing Associations that all selected ecological sites are biologically capable of producing high structure and 2) determine if strong correlations between VOR and standing crop exist across study sites and years. We hypothesized that 1) all selected ecological sites are biologically capable of producing high structure (8.89 cm VOR) at the end of the grazing season when protected from livestock grazing, 2) significant ($P \leq 0.05$) correlations and relationships ($R^2 \geq 0.60$) exist between standing crop and visual obstruction for each ecological site and year studied, 3) expectations developed by the USFS regarding the ability of ecological sites to produce high structure if standing crop is greater than 1,232 $kg \cdot ha^{-1}$ are true, and 4) plant community composition will not change as a result of three years of no grazing.

Study Area

This study was located within Major Land Resource Area (MLRA) 54 and on the DPG, specifically on the Little Missouri National Grasslands (LMNG) of North Dakota and the Grand River National Grasslands (GRNG) of South Dakota (Figure 1). The portion of the LMNG used in this study is managed by the USDA Forest Service, McKenzie and Medora Ranger Districts and covers 404,685 ha. The GRNG is managed by the USDA Forest Service, Grand River Ranger District and comprised of 62,726 ha.

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

Topography, physiography, and geology. According to the USDA Forest Service (2001), the LMNG and GRNG are located on different Geographic Areas. The LMNG is located on both the Badlands and Rolling Prairie Geographic Areas. The Badlands Geographic Area is characterized by complex drainages and draws descending from grassy ridges or butte-like hills. It is a highly erodible, rolling prairie landscape and composed of largely un-vegetated slopes greater than 40%. The elevation of the area ranges from 549 m to 1,097 m above sea level. The topography of the Rolling Prairie Geographic Area is nearly level with rolling hills, with inclusions of scattered buttes and badland landscapes. The GRNG is located on the Grand/Cedar Geographic Area. The topography, similar to parts of the LMNG, consists of level stretches to rolling hills with isolated areas of badland and rock outcrops. Butte escarpments also dot the landscape and the elevation ranges from 709 m to 888 m above sea level (USDA, Forest Service 2001).

MLRA 54 is in the Missouri Plateau of the Great Plains Province in the Interior Plains. The majority of the area is unglaciated; however, the northern and eastern edges of the region have been glaciated. This area is underlain by soft calcareous shales, siltstones, and sandstones of the Tertiary Fort Union Formation and the Fox Hills and Hell Creek units. These units are the primary source of ground water for the area and impermeable Cretaceous shale underlies these aquifers (USDA, Natural Resource Conservation Service 2006).

Soils. The dominant soil orders of MLRA 54 are Mollisols and Entisols with typically a frigid soil temperature regime and ustic soil moisture regime. The mineralogy is usually mixed or smectitic and the soil depth ranges from shallow to very deep. Haplustolls formed in residdum on uplands (Amor and Vebar series) and in alluvial material on stream terraces and upland drainages (Pershall series). Natrustolls (Belfield, Daglum, and Rhoades series) developed on uplands, stream, terraces, and upland drainage-ways on residuum and/or alluvium. Calciustolls (Chama series), Ustorthents (Cabba series), and Ustipsamments (Flasher series) formed in residuum and/or colluvium on uplands. Argiustolls developed in residual materials on uplands (Morton, Reeder, and Regent) and on till plains and moraines (Williams; USDA, Natural Resource Conservation Service 2006). The typical surface textures are loamy, silt loam, and clay loam while the major subsurface texture group is clayey. Soils located in the Badlands Geographic Area of the LMNG are typically multi-layered with exposed soft rock or rock like substances such as siltstones, clay stones, shale, and sandstone. Lignite and scoria may also be present (USDA, Forest Service 2001).

Climate. Since the study area is located near the middle of the North American continent and has few large natural barriers, the area is described as having a semi-arid Continental climate. Air masses are able to move unobstructed across the landscape, resulting in rapid temperature changes. The mean annual precipitation ranges from 36 to 46 cm and the mean annual temperature ranges from 4 to 8°C (USDA, Forest Service 2001).

Precipitation is unpredictable, with most rainfall occurring as thunderstorms during May and June (USDA, Natural Resource Conservation Service 2006). The frost-free period lasts about 127 days while the freeze-free period lasts about 148 days, with the southern edge typically having the longer frost- and freeze-free periods than the northern edge of the region (USDA, Forest Service 2001; and USDA, Natural Resource Conservation Service 2006).

Biota. Native cool-season plant growth begins in late March and continues to early/mid-July. Native warm-season plants begin growing in mid-May and begin to senesce near the end of July. Green-up of cool-season plants may occur in September and October if sufficient moisture is present. Since the study area is located in an area with variable soil and ecological characteristics, a wide variety of native plant species exist. The vegetation in the LMNG and GRNG is dominated by mixed grass prairie and intermixed with short, mid and tallgrasses (USDA, Forest Service 2001).

Common plants characterized as natural prairie vegetation found in the area include western wheatgrass (*Pascopyrum smithii (Rydb.) A. Love*), needle-and-thread (*Hesperostipa comata* (Trin. & Rupr.) Barkworth), green needlegrass (*Nasella viridula* (Trin.) Barkworth), prairie junegrass (*Koeleria macrantha* (Ledeb.) Schult.), threadleaf sedge (*Carex filifolia* Nutt.)

and blue grama (*Bouteloua gracilis* (Willd. Ex Kunth) Lag. Ex Griffiths). Shallow and thin soils are comprised of little bluestem (*Schizachyrium scoparium* (Michx.) Nash), prairie sandreed (*Calamovilfa longifolia* (Hook.) Scribn.), and sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.). Prairie rose (*Rosa arkansana* Porter), leadplant (*Amorpha canescens* Pursh), silver sagebrush (*Artemesia cana* Pursh.) and western snowberry (*Symphoricarpos occidentalis* Hook.) are also interspersed throughout the landscape. Draws and narrow valleys are often comprised of green ash (*Fraxinus pennsylvanica* Marshall), chokecherry (*Prunus virginiana* L.), silver buffaloberry (*Shepherdia argentea* (Pursh) Nutt.), American elm (*Ulmus Americana* L.), and boxelder (*Acer negundo* (L.) Var. negundo). Introduced plant species consist of crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), Kentucky bluegrass (*Poa pratensis* L.), smooth brome (*Bromus inermis* Leyss.), and yellow sweetclover (*Medicago officinalis* (L.) Lam.) (USDA, Natural Resource Conservation Service 2006).

The dominant wildlife species in the area 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 (*Anas platyrhynchos*), and geese (*Branta Canadensis*; USDA, Natural Resource Conservation Service 2006).

Land uses and concerns. There are various land uses in MLRA 54. These include cropland (38% private, 1% Federal), grassland (50% private, 4% Federal), forest (1% private), urban development (1% private), water (3% private), and other (2% private). Farms and ranches make up the majority of the area and produce cash-grain crops as well as livestock. Over half the area produces native vegetation grazed by livestock while about one third of the area is used as dry-farmland to grow small grains (wheat, barley, oats, rye, and flax) as well as corn for silage and grain. Alfalfa and sunflowers are also commonly grown in the area (USDA, Natural Resource Conservation Service 2006).

The major resource concerns of the area focus on wind and water erosion, as well as the maintenance of soil qualities such as organic matter content, soil productivity, soil moisture, and saline seeps. Conservation practices used on croplands include crop residue management and minimum-till and no-till systems to reduce the need for summer fallow tillage. Cover crops, vegetative and artificial windbreaks, nutrient and soil salinity management, prescribed grazing, fencing, and water developments are other practices utilized in the area (USDA, Natural Resource Conservation Service 2006).

Loamy ecological sites. Loamy ecological sites occur on gently undulating to rolling sedimentary uplands. The slope will range from 2 to 20% on alluvial fans, flats, or hills. The water table may be up to 1.8 m deep and runoff class varies from medium to very high. Since these sites are uplands, flooding and ponding does not occur (USDA, Natural Resource Conservation Service 2010). The surface layer should form a ribbon less than 2.5 cm in length of silt loam or loam while the subsoil layers will form a ribbon of similar length of silt loam to clay loam. These upland sites will have a subsoil that is none to slightly effervescent (Sedivec and Printz 2012). The soils are typically silt loam to clay loam textured in the subsoil and well drained, having formed in soft siltstone, sandstone, and alluvium. Water-flow patterns may exist and be broken, irregular in appearance or discontinuous with debris dams/vegetative barriers, and rills and gullies may form if there is not a proper amount of vegetative cover. Cryptobiotic crusts are expected and some pedestalled plants may be present, though should not be very evident and should only occur about 5% of the time. Erosion should not be a main concern and the soil surface should be stable and intact (USDA, Natural Resource Conservation Service 2010).

The reference plant community is characterized as having green needlegrass, western wheatgrass, porcupine grass, prairie junegrass, big bluestem (*Andropogon gerardii* Vitman), American vetch (*Vicia americana* Muhl. Ex. Willd.), heath aster (*Symphyotrichum ericoides* (L.) G. L. Nesom), prairie coneflower (*Ratibida columnifera* (Nutt.) Woot. & Standl.), purple prairie clover (*Dalea purpurea* Vent.), stiff sunflower (*Helianthus pauciflorus* Nutt.), and leadplant. Phytomass production will range from 2,315 to 2850 kg·ha^{-1} in the east and 1,825 to 2,150 kg·ha^{-1} in the west (Sedivec and Printz 2012).

Thin loamy ecological sites. Thin loamy ecological sites occur on moderately steep to steep sedimentary uplands. The slope will range from 6 to 35% on hills, knolls, and ridges. These sites have a medium to high runoff class. Since these sites are on uplands, flooding and ponding does not occur (USDA, Natural Resource Conservation Service 2010). The surface layer should form a ribbon less than 2.5 cm in length of silt loam or loam with the subsoil layers forming a ribbon of similar length of silt loam to clay loam. These soils should have none to strong effervescence in the surface layer and strong to violent effervescence in the subsoil (Sedivec and Printz 2012). The soils are commonly calcareous silt loam to calcareous fine sandy loam and well drained, having formed in soft siltstone and loess or glacial till deposits. Pedestalled plants may be common due to the natural instability of the soil. Water-flow patterns may exist and be broken, irregular in appearance or discontinuous with debris dams/vegetative barriers, and rills, gullies, and slumps may form if there is not a proper amount of vegetative cover. Cryptobiotic crusts are expected while the soil surface is unstable. Due to instability of the site, erosion and deposition is highly likely to occur. Sub-surface soil layers are also slightly restrictive to water movement and root penetration, limiting plant growth (USDA, Natural Resource Conservation Service 2010).

The reference plant community should include little bluestem, porcupine grass (*Hesperostipa spartea* (Trin.) Barkworth), sideoats grama, green needlegrass, plains muhly (*Muhlenbergia cuspidata* (Torr. Ex Hook.) Rydb.) blue grama, sedges (*Carex* L.), purple coneflower, American vetch, cutleaf ironweed (*Rudbeckia laciniata* L.), leadplant, and fringed sagewort (*Artemisia frigida* Willd.). Phytomass production will range from 1,950 to 2,400 kg·ha^{-1} in the east and 1,250 to 1,500 kg·ha^{-1} in the west (Sedivec and Printz 2012).

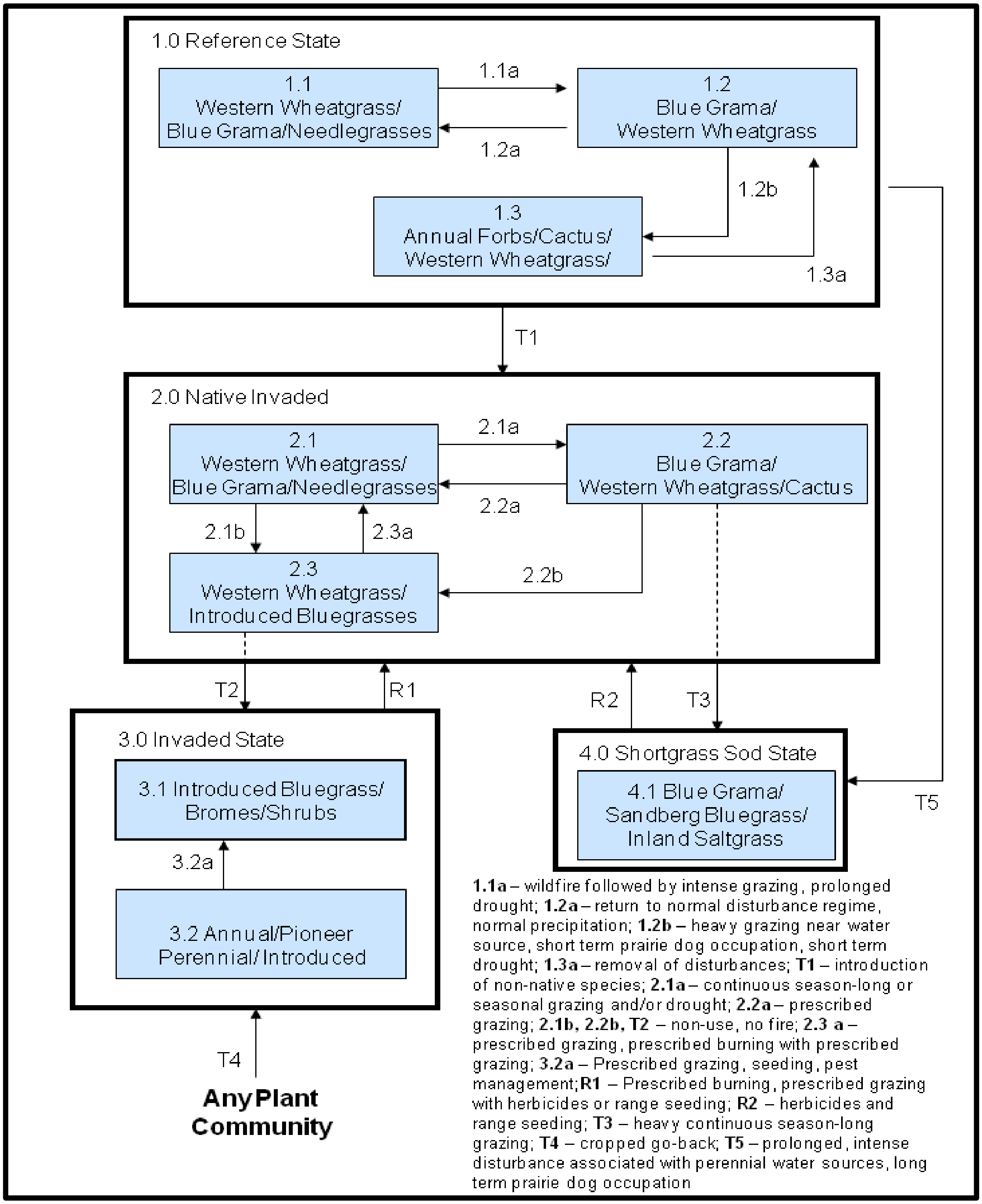
Claypan ecological sites. Claypan ecological sites generally occur on gently undulating to rolling sedimentary uplands. The slope on this site may range from 0 to 25% on alluvial fans, flats, or hills. The water table may be up to 1.8 m deep and the runoff class varies from medium to very high. Since these sites are on uplands, long-term flooding and ponding does not occur (USDA, Natural Resource Conservation Service, 2010). The surface layer may range in depth from 15 to 35 cm and the subsoil should form at least a 5 cm long ribbon of clay loam to clay (Sedivec and Printz 2012). The soils are typically silty clay to clay textured in the subsoil and moderately well to well drained, having formed in siltstone, shales, and alluvium. The B_{tn} horizon associated with claypan sites will have a columnar structure and may be high in sodium. There should be no evidence of rilling, wind-scoured areas, or pedestalled plants. Water-flow patterns, however, may be broken, irregular in appearance, or discontinuous with several debris dams and/or vegetative barriers. Nonetheless, the soil surface should still be intact. The major concern on these sites is water erosion, especially on sites with slopes greater than 9%. If the soil surface layer is lost, species composition and/or production may shift (USDA, Natural Resource Conservation Service 2010).

The reference plant community of claypan ecological sites generally consists of western wheatgrass, blue grama, green needlegrass, threadleaf sedge, cudweed sagewort, heath aster, goldenrod (*Oligoneuron spp.* Small), silverleaf scurfpea (*Psoralidium tenuiflorum* (Pursh) Rydb.), fringed sagewort, and prairie rose. Phytomass production will range from 1,720 to 2,050 kg·ha^{-1} in the east and 1,250 to 1,335 kg·ha^{-1} in the west (Sedivec and Printz 2012).

Methods and Design

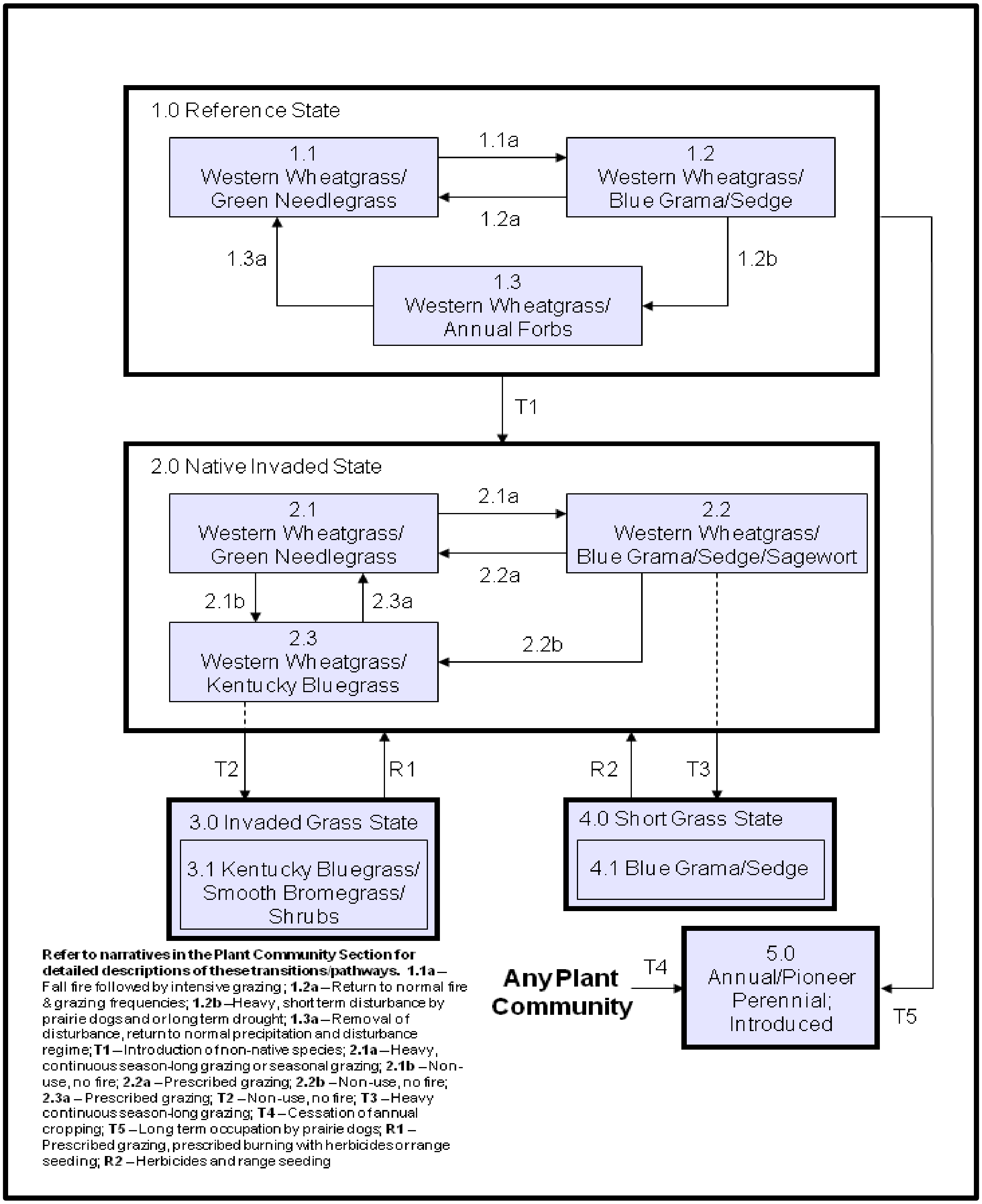
Three ecological sites (claypan, loamy, and thin loamy) were selected on the GRNG and LMNG to determine if they were biologically capable of producing high structure (8.89 cm). These sites were selected based on criteria and methods established by the Natural Resource Conservation Service (NRCS) for classifying ecological sites. These three ecological sites were selected because 1) they are common throughout the National Grasslands, 2) their mean annual productivity is greater than the USFS minimum production of 1,232 kg·ha^{-1} to achieve high structure, and 3) they represent low (claypan), mid (thin loamy) and high (loamy) phytomass production sites. Study plots were verified by NRCS personnel to ensure they were correctly identified. Eight study plots were selected for each ecological site at each location, yielding 48 total study plots (3 ecological sites x 8 plots x 2 study locations = 48 plots). Each plot was selected based on vegetative phases closest to the historic climax plant community as described in the NRCS state-and-transition models for each ecological site: claypan (Figure 2), loamy (Figure 3), thin loamy (Figure 4; USDA, Natural Resource Conservation Service 2012). Each plot was fenced using a 60 m x 60 m design to exclude the grazing variable and a 200 m transect was laid out in a 50 m x 50 m square design within the exclosure.

Vegetative structure was designated as VOR and measured with a modified Robel pole (Robel et al. 1970). Modifications included altering the bandwidth from one decimeter to one inch (2.54 cm) and reading the last visible bandwidth so that one inch (2.54 cm) would be the lowest possible reading as in accordance with the US Forest Service (2001) protocol. Each VOR station was read at a distance of four m from the Robel pole, with the observer’s eyes at a height of one m and measurements rounded to the nearest inch.



1.1a – wildfire followed by intense grazing, prolonged drought; **1.2a** – return to normal disturbance regime, normal precipitation; **1.2b** – heavy grazing near water source, short term prairie dog occupation, short term drought; **1.3a** – removal of disturbances; **T1** – introduction of non-native species; **2.1a** – continuous season-long or seasonal grazing and/or drought; **2.2a** – prescribed grazing; **2.1b, 2.2b, T2** – non-use, no fire; **2.3 a** – prescribed grazing, prescribed burning with prescribed grazing; **3.2a** – Prescribed grazing, seeding, pest management; **R1** – Prescribed burning, prescribed grazing with herbicides or range seeding; **R2** – herbicides and range seeding; **T3** – heavy continuous season-long grazing; **T4** – cropped go-back; **T5** – prolonged, intense disturbance associated with perennial water sources, long term prairie dog occupation

Figure 2. State-and-transition model diagram for the claypan ecological site for Major Land Resource Area 54 (USDA, Natural Resource Conservation Service 2012).



Refer to narratives in the Plant Community Section for detailed descriptions of these transitions/pathways. 1.1a – Fall fire followed by intensive grazing; **1.2a** – Return to normal fire & grazing frequencies; **1.2b** – Heavy, short term disturbance by prairie dogs and or long term drought; **1.3a** – Removal of disturbance, return to normal precipitation and disturbance regime; **T1** – Introduction of non-native species; **2.1a** – Heavy, continuous season-long grazing or seasonal grazing; **2.1b** – Non-use, no fire; **2.2a** – Prescribed grazing; **2.2b** – Non-use, no fire; **2.3a** – Prescribed grazing; **T2** – Non-use, no fire; **T3** – Heavy continuous season-long grazing; **T4** – Cessation of annual cropping; **T5** – Long term occupation by prairie dogs; **R1** – Prescribed grazing, prescribed burning with herbicides or range seeding; **R2** – Herbicides and range seeding

Figure 3. State-and-transition model diagram for the loamy ecological site in Major Land Resource Area 54 (USDA, Natural Resource Conservation Service 2012).

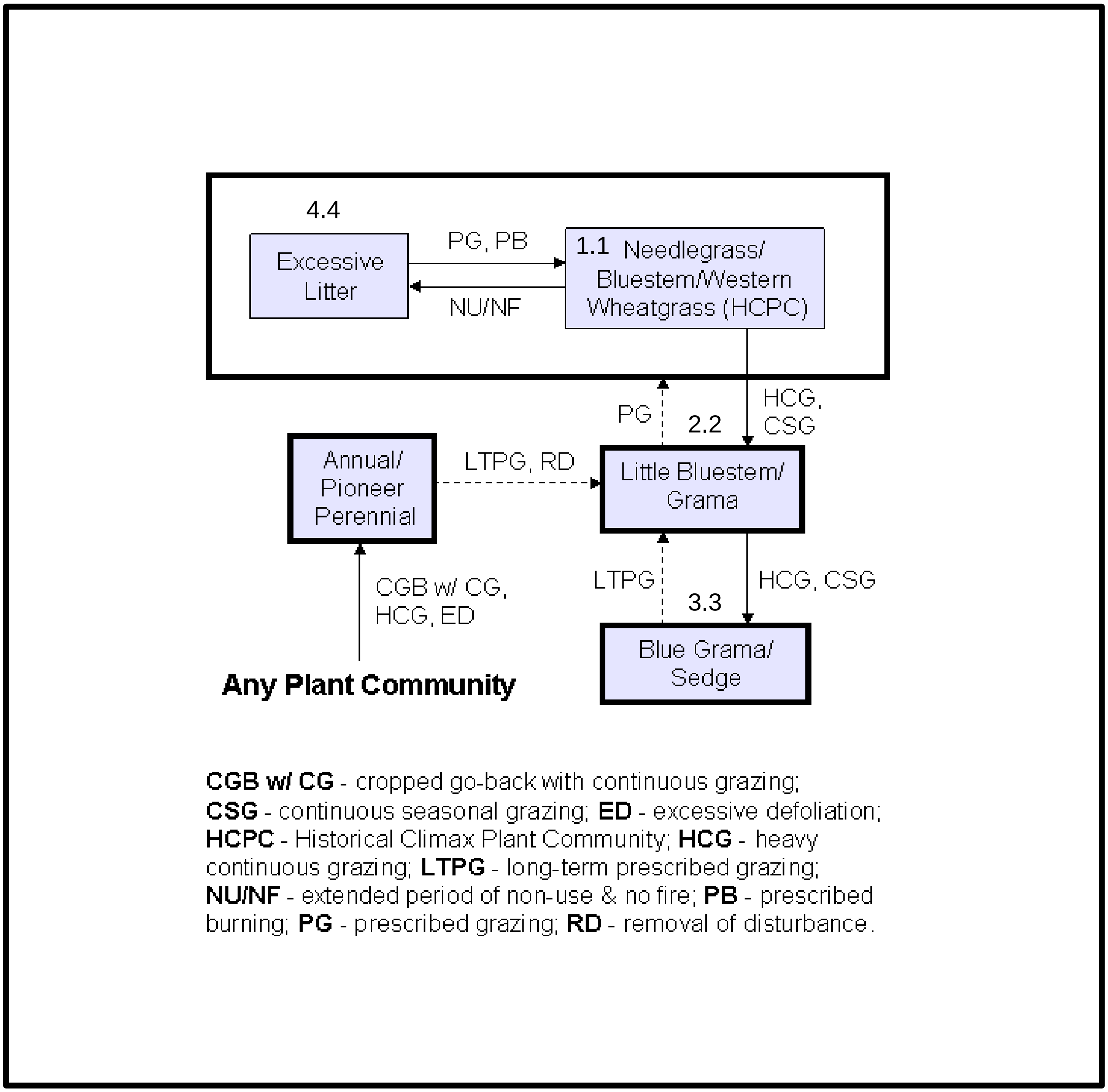


Figure 4. State-and-transition model diagram for thin loamy ecological site in Major Land Resource Area 54 (USDA, Natural Resource Conservation Service 2012).

VORs were collected every 10 m along the 200 m transect (20 stations) for each study plot. Each VOR station along the transect was the average of four readings taken from each cardinal direction (4). All 20 stations were averaged to create a mean standing crop height per study plot. Pre-data measurements were taken in October, 2011 and samples used in analyses were collected in late July during peak phytomass production (Whitman et al. 1951, Sedivec et al. 2009, Sedivec et al. 2010) and mid- to late October to represent the end of the grazing season in 2012, 2013, and 2014. Visual obstruction reading mean and standard error (SE) were developed for each ecological site across all years to determine the biological capability of sites to achieve high structure (VOR > 8.89 cm). Sites were considered biologically capable if the standard error contained the 8.89 cm threshold. Pre-data VOR was collected in early October 2011 to determine VOR status prior to the excluding of grazing (Appendix B).

Aboveground biomass was determined by clipping standing crop, including both live and standing dead material. Vegetation was clipped to ground level using a 0.178 m^2 circular frame in late July and mid- to late October in 2012, 2013, and 2014. Circular frames were clipped 0.5 m off center from the VOR to prevent vegetative destruction for future data collection periods. Pre- and post-data were clipped every 20 m along the 200 m transect and sorted by graminoid species, native shrubs, introduced shrubs, native forbs, and introduced forbs as well as standing dead and litter in late July 2012 (pre) and 2014 (post). Vegetation clipped in July 2013, and mid- to late October 2012, 2013, and 2014 was clipped every 40 m and sorted into live, standing dead, and litter material. After vegetation was collected, it was oven dried at 60°C for 72 hours and weights recorded to the nearest 0.1 g to determine standing crop and phytomass production. Weights were then converted to $kg \cdot ha^1$ for each study plot and averaged for each ecological site.

The statistical design was a stratified, randomized design with locations as blocks. Plots were systematically located by ecological site and historical climax stage, and the starting point randomly selected within the ecological site. SAS® Enterprise Guide (SAS Institute Software 2013, Version 6.1, SAS Inc., Cary, NC) was used to create linear regression models to evaluate the relationship between VOR and standing crop, where VOR was the independent variable and standing crop the dependent variable. Significance was assessed at an alpha of $P \leq 0.05$. VOR was analyzed by one standard error based on the generated sample mean for each ecological site to determine if ecological sites were biologically capable of producing 8.89 cm (3.5 inches) of high structure during each collection period.

Plant community composition was assessed on a dry-weight basis. Multivariate techniques in PC-Ord v.6 (MJM Software Design, Gleneden Beach, OR, USA) were used to summarize multi-dimensional plant community responses, assess whether plant community composition responses were influenced by year effects and litter accumulation (using a permutation-based MANOVA [PerMANOVA]), and identify the specific plant species driving these community responses (using non-metric multidimensional scaling [NMS]). Relative Sorensen's distance measure was used in all analyses. The PerMANOVA assessed significance based on 4999 randomizations and the proportion of randomized trials with an indicator cover greater or equal to the observed cover value (Anderson 2001). NMS procedures involved 20 runs with real data (Anderson 2001). NMS procedures involve these criteria for thoroughness: 1) 500 iterations, 2) an instability criterion of 1×10^{-7}, 3) starting axes of 6, 4) 250 runs with real data, and 5) 250 randomized runs for the randomization test. Dimensionality for the NMS solution was based these criteria: 1) a stress less than 20, 2) a randomization test result of $P < 0.05$ for each axis, and 3) at least a 5 point reduction in stress for each axis.

Results

Climate. Average annual precipitation ranged from 90% to 181% of the long-term average between 2011 and 2014 at the GRNG. The growing season (April – September) precipitation ranged from 100% to 180% of normal between 2011 and 2014. Average annual precipitation in 2012 was slightly less than the long-term average (Table 1; Hettinger, ND, Lemmon, SD; NDAWN 2015, NOAA 2015). Average annual precipitation at the LMNG ranged from 72% to 135 of the long-term average between 2011 and 2014. Growing season precipitation was lowest in 2012 (72%; Table 2; Watford City, ND, Sidney, MT; NDAWN 2015, NOAA 2015).

Table 1. Monthly precipitation (mm) for 2011, 2012, 2013, 2014, and long-term average for plots located at the Grand River National Grasslands (NDAWN 2015; NOAA 2015).

Month	**2011**	**2012**	**2013**	**2014**	**Long-Term Average (1981-2010)**
January	8.9	6.2	1.4	3.0	9.9
February	15.5	14.0	3.6	3.2	12.3
March	17.2	9.1	14.5	13.2	22.9
April	71.6	71.5	21.5	40.6	34.3
May	106.8	49.9	216.9	39.2	57.9
June	79.5	50.5	101.5	130.2	87.6
July	45.7	92.1	57.9	18.2	51.9
August	53.6	47.8	60.6	140.2	46.2
September	7.9	1.3	103.1	28.8	33.5
October	26.7	16.7	145.8	4.2	27.4
November	1.0	4.6	4.6	9.8	15.2
December	5.6	4.5	10.2	3.2	9.7
Annual	440.1 (108%)	368.6 (90%)	741.4 (181%)	433.8 (106%)	408.9

Table 2. Monthly precipitation (mm) for 2011, 2012, 2013, 2014, and long-term average for plots located at the Little Missouri National Grasslands (NDAWN 2015; NOAA 2015).

Month	**2011**	**2012**	**2013**	**2014**	**Long-Term Average (1981-2010)**
January	31.9	3.0	6.7	2.7	11.6
February	11.0	5.3	2.9	3.8	12.3
March	35.4	1.7	21.1	11.6	21.2
April	61.6	32.6	5.1	31.9	36.6
May	154.6	50.9	142.4	82.4	63.5
June	48.0	48.4	83.2	42.4	70.1
July	90.6	47.9	27.3	15.1	47.6
August	22.9	21.0	74.2	97.9	33.9
September	20.7	0.4	44.5	28.8	26.7
October	11.9	52.1	53.2	5.6	20.1
November	5.8	13.1	10.4	11.9	14.0
December	5.6	10.9	14.1	3.6	12.6
Annual	500.0 (135%)	201.2 (72%)	485.0 (131%)	337.7 (91%)	370.1

Standing crop growth characteristics. *Growing season disappearance.* In 2012, mean standing crop decreased on all ecological sites at both GRNG and LMNG from July (expected peak standing crop) to October (post-grazing season). Phytomass on the claypan sites on the GRNG and all sites on the LMNG increased, likely due to precipitation events, while loamy and thin loamy sites at the GRNG decreased from July to October. Visual obstruction generally decreased from summer to fall on all ecological sites in 2012 (Tables 3 and 4).

Mean standing crop increased on thin loamy and claypan sites on the LMNG, while phytomass decreased from July to October, 2013. However, there was no change for the claypan sites on the GRNG. Percent change could not be calculated on loamy and thin loamy sites at the GRNG and loamy sites at the LMNG due to lack of data. VOR consistently decreased by a minimum of 35 percent on all ecological sites at the GRNG and LMNG. A large decrease in

VOR at the GRNG occurred due to heavy snowfall, which packed down the vegetation, resulting in an unexpectedly low VOR. (Tables 5 and 6).

Table 3. Mean standing crop (SC), phytomass, and visual obstruction reading (VOR) at the Grand River National Grasslands (GRNG) and Little Missouri National Grasslands (LMNG) in July, 2012.

Location	**GRNG**			**LMNG**		
Ecological site	**Loamy**	**Thin Loamy**	**Claypan**	**Loamy**	**Thin Loamy**	**Claypan**
Mean SC ($kg \cdot ha^{-1}$)	2,930	1,950	2,510	2,947	1,988	2,342
Phytomass ($kg \cdot ha^{-1}$)	2,263	1,442	1,730	1,745	1,215	1,265
~VOR (cm)	10.7	7.9	10.5	9.8	8.4	8.3

Table 4. Mean standing crop (SC), phytomass, and visual obstruction reading (VOR) for October 2012, and change between July and October at the Grand River National Grasslands (GRNG) percent and Little Missouri National Grasslands (LMNG) in 2012.

Location	**GRNG**			**LMNG**		
Ecological site	**Loamy**	**Thin Loamy**	**Claypan**	**Loamy**	**Thin Loamy**	**Claypan**
Mean SC ($kg \cdot ha^{-1}$)	1976 (-32.6%)	1505 (-22.8%)	2119 (-15.6%)	2124 (-27.9%)	1662 (-16.4%)	2124 (-9.3%)
Phytomass ($kg \cdot ha^{-1}$)	1757 (-22.4%)	1189 (-17.5%)	1825 (+5.5%)	1945 (+11.5%)	1414 (+16.4%)	1428 (+12.9%)
~VOR (cm)	8.3 (-22.4%)	6.2 (-21.5%)	8.7 (-17.1%)	9.9 (+ 1.0%)	7.3 (-13.1%)	8.0 (-3.6%)

Table 5. Mean standing crop (SC), phytomass, and visual obstruction reading (VOR) at the Grand River National Grasslands (GRNG) and Little Missouri National Grasslands (LMNG) in July, 2013.

Location	**GRNG**			**LMNG**		
Ecological site	**Loamy**	**Thin Loamy**	**Claypan**	**Loamy**	**Thin Loamy**	**Claypan**
Mean SC ($kg \cdot ha^{-1}$)	N/A[1]	N/A[1]	2317	2805	2518	2561
Phytomass ($kg \cdot ha^{-1}$)	N/A[1]	N/A[1]	1901	2485	2368	2215
~VOR (cm)	19.2	11.0	14.9	17.2	11.2	11.7

[1] N/A indicated not available

Table 6. Mean standing crop (SC), phytomass, and visual obstruction reading (VOR) for October 2013, and percent change between July and October at the Grand River National Grasslands (GRNG) and Little Missouri National Grasslands (LMNG) in 2013.

Location	**GRNG**			**LMNG**		
Ecological site	**Loamy**	**Thin Loamy**	**Claypan**	**Loamy**	**Thin Loamy**	**Claypan**
Mean SC ($kg \cdot ha^{-1}$)	2840 NA[1]	1404 NA	2178 (- 6.0%)	2968 (+ 5.8%	2532 (+ 0.6%)	2590 (+ 1.1%)
Phytomass ($kg \cdot ha^{-1}$)	1087 NA	2608 NA	1901 (- 0.0%)	2601 (+ 4.7%)	2105 (- 11.1%)	2242 (- 1.2%)
~VOR (cm)	7.8 (- 59.4%)	5.7 (- 51.2%)	7.7 (- 48.2%)	9.2 (- 46.5%)	7.2 (- 35.7%)	7.2 (-38.5%)

[1] N/A indicated not available

Mean standing crop and phytomass only decreased on thin loamy sites from July to October, 2014. On claypan sites at the GRNG and all ecological sites at the LMNG, mean standing crop and phytomass increased. Loamy sites at the GRNG showed little change between standing crop and phytomass between the two collection periods. However, visual obstruction decreased on all ecological sites except loamy sites at the LMNG (Tables 7 and 8).

Table 7. Mean standing crop (SC), phytomass, and visual obstruction reading (VOR) at the Grand River National Grasslands (GRNG) and Little Missouri National Grasslands (LMNG) in July, 2014.

Location	**GRNG**			**LMNG**		
Ecological site	**Loamy**	**Thin Loamy**	**Claypan**	**Loamy**	**Thin Loamy**	**Claypan**
Mean SC ($kg·ha^{-1}$)	4,650	3,220	3,452	3,026	2,116	2,530
Phytomass ($kg·ha^{-1}$)	4,503	2,946	3,255	2,236	1,694	1,949
~VOR (cm)	20.7	11.1	21.3	13.8	10.2	11.6

Table 8. Mean standing crop (SC), phytomass, and visual obstruction reading (VOR) for October 2014 collection period with percent change in production from July at the Grand River National Grasslands (GRNG) and Little Missouri National Grasslands (LMNG).

Location	**GRNG**			**LMNG**		
Ecological site	**Loamy**	**Thin Loamy**	**Claypan**	**Loamy**	**Thin Loamy**	**Claypan**
Mean SC ($kg·ha^{-1}$)	4717 (+ 1.4%)	2,548 (- 20.9%)	3838 (+ 11.1%)	3,913 (+29.3%)	2,895 (+36.8%)	3,141 (+24.2%)
Biomass ($kg·ha^{-1}$)	4,325 (-4.0%)	2,124 (- 27.9%)	3,285 (+ 0.9%)	3,402 (+ 52.1%)	2,547 (+50.4%)	2704 (+38.7%)
~VOR (cm)	18.7 (-9.7%)	8.6 (-22.5%)	13.5 (-36.6%)	14.8 (+7.2%)	8.8 (-13.7%)	9.4 (-19.0%)

Standing crop and VOR correlations. The linear relationship between standing crop and visual obstruction varied among ecological sites, between study locations, and among years with no consistent correlation patterns ($n = 8$; Appendix A). Ecological sites with a minimum one year linear relationship ($P < 0.05$; $R2 \geq 0.60$) at the GRNG were claypan, thin loamy, and loamy ecological sites. Only the claypan and thin loamy sites had a minimum one year linear relationship at the LMNG. However, several sites showed no linear correlation between standing crop and visual obstruction for one or more years of the study, including the claypan and thin loamy sites at the GRNG, and loamy and claypan sites at the LMNG (Table 9).

Table 9. Coefficients of determination (R^2) of the relationship between visual obstruction and standing crop for each ecological site (n = 8) at the Grand River National Grasslands (GRNG) and Little Missouri National Grasslands (LMNG) in October, 2012, 2013, and 2014.

	GRNG			**LMNG**		
October	**Loamy**	**Thin loamy**	**Claypan**	**Loamy**	**Thin loamy**	**Claypan**
2012	0.52	0.54	0.96[a]	0.57	0.58	0.81[a]
2013	0.54	0.75[a]	NC[b]	NC[b]	0.49	0.58
2014	0.66[a]	NC[b]	0.58	NC[b]	0.92[a]	NC[b]

[a] Acceptable correlations between standing crop and visual obstruction ($P \leq 0.05$; $R^2 \geq 0.60$)
[b] NC = no correlation ($P > 0.05$)

For all sites that displayed an acceptable linear relationship ($P \leq 0.05$; $R^2 \geq 0.60$), standing crop production required to achieve high structure ranged from 2,046 to 3,104 kg·ha^{-1} across ecological sites (Table 10). Claypan sites required 2,046 to 2,183 kg·ha^{-1} of standing crop, depending on location (LMNG or GRNG; respectively). Thin loamy sites should be capable of achieving high structure with 2,425 kg·ha^{-1} of standing crop or more. Loamy sites needed to produce the most standing crop to achieve high structure (3,104 kg·ha^{-1}; Table 10). When combining the five best models, mean standing crop required to achieve high structure was 2,534 kg·ha^{-1}, with a standard error of ±205.3.

Table 10. Regression models by ecological sites that displayed a linear relationship between visual obstruction and standing crop ($P < 0.05$; $R^2 \geq 0.60$) for the October collection period in 2012, 2013 and 2014.

Ecological site	**Location**	**Year**	**Regression model**	**X kg·ha^{-1} = 8.89 cm**
Claypan	GRNG	2012	$Y = 344.1x - 877.3$	2,183
Claypan	LMNG	2012	$Y = 233.0x - 25.4$	2,046
Thin loamy	GRNG	2013	$Y = 318.3x - 405.1$	2,425
Loamy	GRNG	2014	$Y = 173.5x + 1{,}471.9$	3,104
Thin loamy	LMNG	2014	$Y = 400.0x - 642.2$	2,914

Biological capability. Loamy and claypan ecological sites achieved high structure in October, 2012 (Table 11). In 2013, only the claypan sites at the GRNG and loamy sites at the LMNG produced high structure (Table 12). All ecological sites were biologically capable of producing high structure in 2014, with some sites nearly doubling their mean VOR from the previous year. Thin loamy ecological sites only achieved high structure in 2014 (Table 13).

Table 11. Mean visual obstruction reading (VOR) and standard error (SE) in cm for all ecological sites at the Grand River National Grasslands and Little Missouri National Grasslands in October, 2012.

	GRNG			**LMNG**		
	Loamy	**Thin loamy**	**Claypan**	**Loamy**	**Thin loamy**	**Claypan**
Mean VOR	8.3	6.2	8.7	9.9	7.3	8.0
SE	± 0.77 (7.53-9.07)	± 1.27 (4.93-7.47)	± 0.59 (8.11-9.29)	± 0.83 (8.84-10.96)	± 1.06 (6.24-8.36)	± 1.10 (6.90-9.10)

Table 12. Mean visual obstruction reading (VOR) and standard error (SE) in cm for all ecological sites at the Grand River National Grasslands and Little Missouri National Grasslands in October, 2013.

	GRNG			**LMNG**		
	Loamy	**Thin loamy**	**Claypan**	**Loamy**	**Thin loamy**	**Claypan**
Mean VOR	7.8	5.7	7.7	9.2	7.2	7.2
SE	± 0.44 (7.36-8.24)	± 0.65 (5.05-6.35)	± 1.22 (6.48-8.92)	± 0.78 (8.42-9.98)	± 1.02 (6.18-8.22)	± 0.78 (6.42-7.98)

Table 13. Mean visual obstruction reading (VOR) and standard error (SE) in cm for all ecological sites at the Grand River National Grasslands and Little Missouri National Grasslands in October, 2014.

	GRNG			**LMNG**		
	Loamy	**Thin loamy**	**Claypan**	**Loamy**	**Thin loamy**	**Claypan**
Mean VOR	18.7	8.6	13.5	14.8	8.8	9.4
SE	± 1.65 (17.05-20.35)	± 0.71 (7.89-9.31)	± 1.34 (12.16-14.84)	± 1.06 (13.74-15.86)	± 0.76 (8.04-9.56)	± 0.72 (8.86-10.12)

Plant community. Plant community characteristics for all ecological sites were evaluated based on differences between year effects on study locations, differences in plant community variability between study location, and changes in species abundance at each ecological site. Similarity indices and plant community phase were also evaluated (Appendix C). Year effects on plant community composition were assessed at the GRNG and LMNG for impact of three years no grazing. Significant (*P* = 0.0062) year effects occurred at the GRNG. The NMS analysis found that 50.2% of the variance was represented by Axis 1 and 24.2% of the variance was represented by axis 2. Overall, 74.4% of the variation was explained by both axes (Figure 5). Significant (*P* = 0.0358) year effects also occurred between 2012 and 2014 at the LMNG. Axis 1 explained 64.7% of the variation and Axis 2 explained 15.9% of the variation; overall, 80.7% of the variation was explained by both axes (Figure 6)

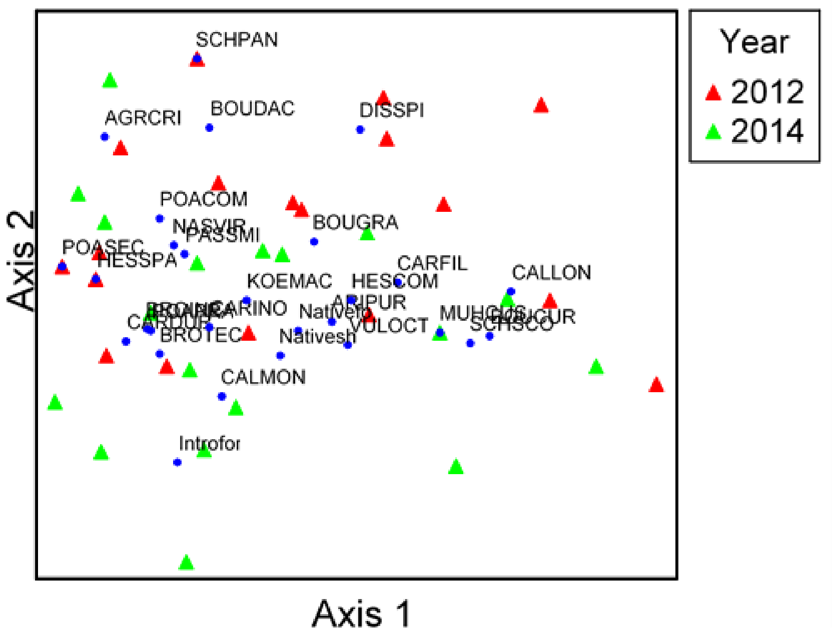


Figure 5. NMS ordination for year effects on plant community composition at all ecological sites at the Grand River National Grasslands (GRNG). Blue dots represent species.

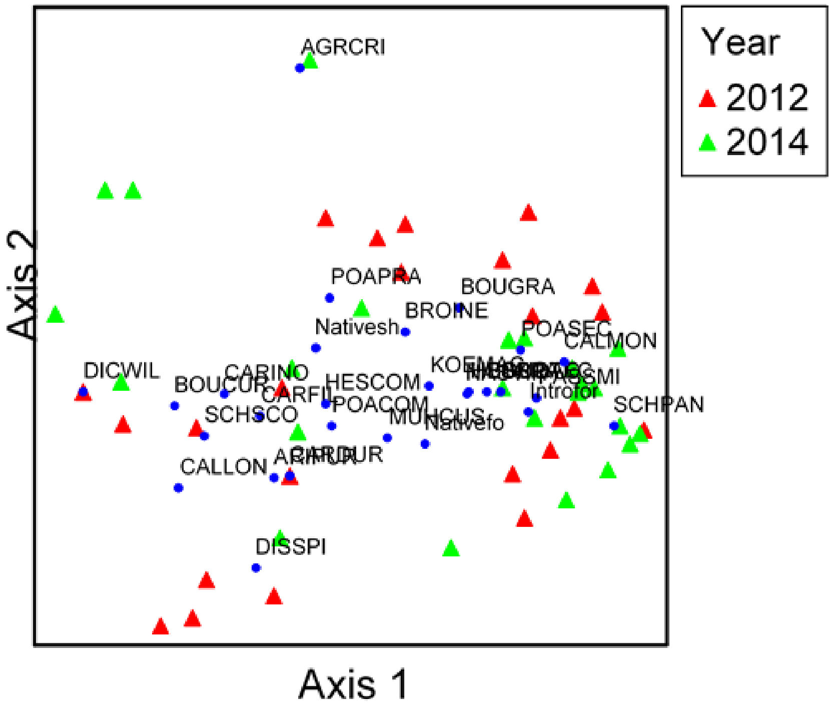


Figure 6. NMS ordination for year effects on plant community composition at all ecological sites at the Little Missouri National Grasslands (LMNG). Blue dots represent species.

Differences in plant community variability were also significant between the GRNG and LMNG at each ecological site (*P* = 0.0002). On loamy sites, Axis 1 explained 74.4% of the variability and Axis 2 explained 16.1%; overall, 90.5% of the variation was explained by both axes. (Figure 7). On thin loamy sites, Axis 1 explained 55.3% of the variation and Axis 2 explained 19.3%; overall, 74.7% of the variation was explained by both axes (Figure 8). On claypan sites, Axis 1 explained 76.3% of the variation and Axis 2 explained 15.2%; overall, 91.5% of the variation was explained by both axes (Figure 9).

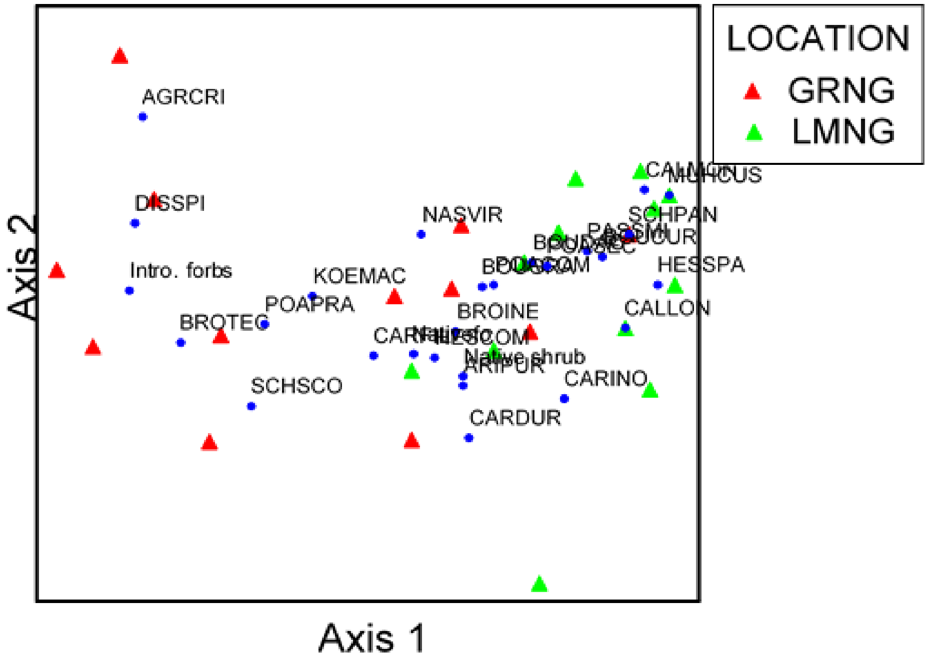


Figure 7. NMS ordination for location effects between the Grand River National Grasslands (GRNG) and the Little Missouri National Grasslands (LMNG) on plant community composition at loamy ecological sites. Blue dots represent species.

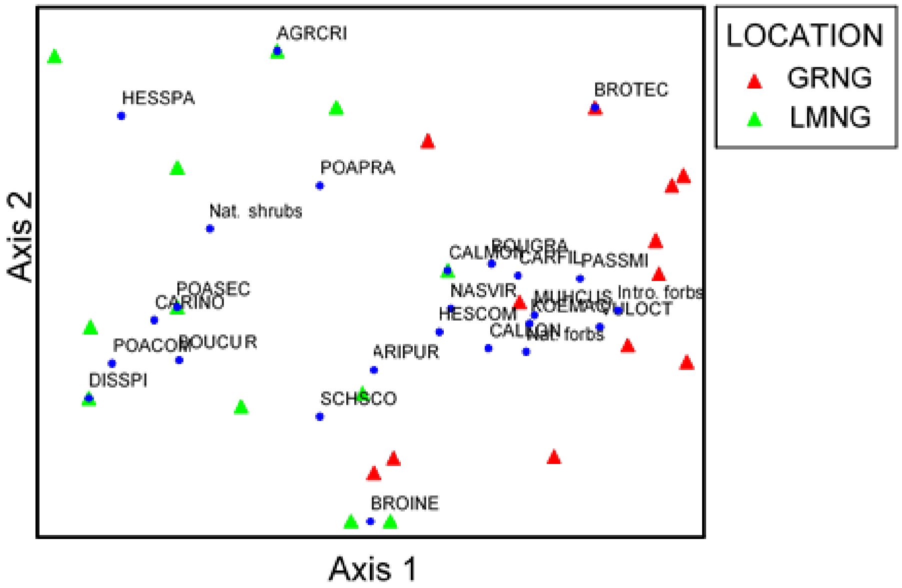


Figure 8. NMS ordination for location effects between the Grand River National Grasslands (GRNG) and the Little Missouri National Grasslands (LMNG) on plant community composition at thin loamy ecological sites. Blue dots represent species.

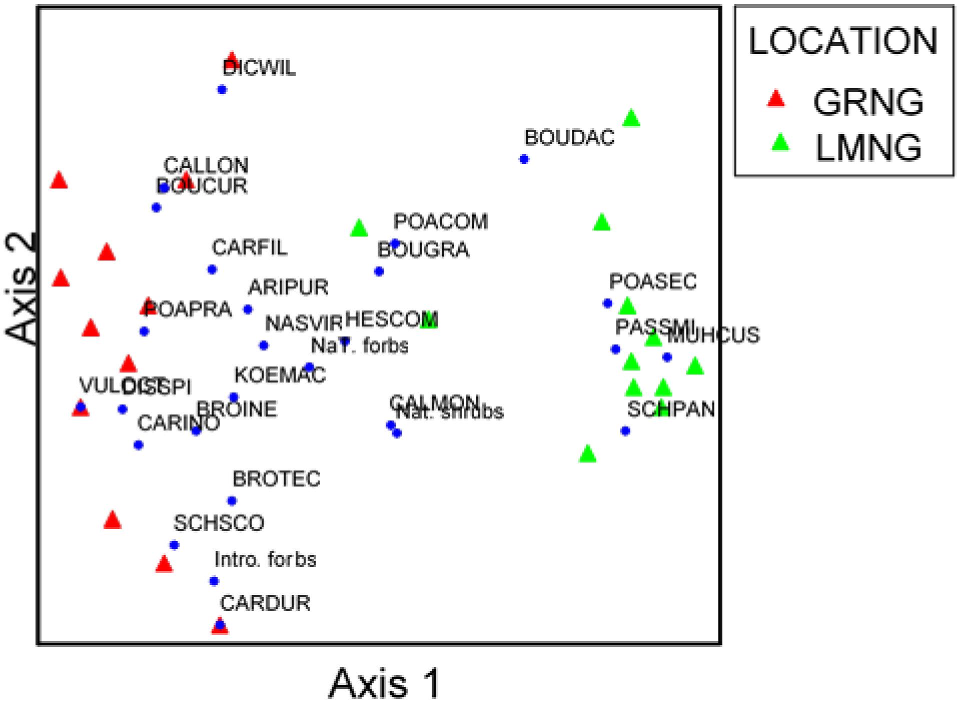


Figure 9. NMS ordination for location effects between the Grand River National Grasslands (GRNG) and Little Missouri National Grasslands (LMNG) on plant community composition at claypan ecological sites. Blue dots represent species.

Year effect significance on plant community variability was evaluated at all ecological sites. Year effects occurred at loamy (*P* = 0.0946) and claypan (*P* = 0.0110) ecological sites at the GRNG and thin loamy (*P* = 0.0004) and claypan sites (*P* = 0.0604) at LMNG. Ordination configurations did not meet criateria for ecological sites at the GRNG; however, NMS ordinations were able to be computed for ecological sites at the LMNG, showing differences in plant community variability between 2012 and 2014. Table 14 lists ecological sites with their associated P-values developed by PerMANOVA results.

Table 14. P-value regarding strength of relationship in year effects at each ecological site from PerMANOVA results.

	GRNG			LMNG		
Ecological site	Loamy	Thin Loamy	Claypan	Loamy	Thin Loamy	Claypan
P-value	0.0946	0.4546	0.0110	0.3712	0.0004	0.0604

Despite the inability for NMS to be constructed for ecological sites at the GRNG, cool- and warm- season grasses and native and non-native species changed in abundance after three years of no livestock grazing. At loamy ecological sites, crested wheatgrass, Kentucky bluegrass, and western wheatgrass increased by 215.8%, 61.4%, and 26.6%; respectively, at the expense of blue grama (-76.7%), green needlegrass (-57.9%), threadleaf sedge (-39.1) and needle-and-thread (-22.6%). On thin loamy sites, Kentucky bluegrass, little bluestem, plains muhly, and western wheatgrass increased by 18.5%, 32.9%, 180.0%, and 9.5%. Species that decreased were blue grama (-16.1%), needle-and-thread (-2.3%), prairie sandreed (-95.8%), sideoats grama (-23.1%) and threadleaf sedge (-44.4%). Green needlegrass did not change in abundance on thin loamy sites between 2012 and 2014. On claypan ecological sites, needle-and-thread and western wheatgrass increased by 300% and 42.1%; respectively, at the expense of blue grama (-81.2%), green needlegrass (-58.0%), and Kentucky bluegrass (-58.5%; Table 15).

Table 15. Percent change in plant species abundance (%) at all ecological sites on the Grand River National Grasslands between July 2012 and July 2014.

	Loamy			Thin Loamy			Claypan		
Species	2012	2014	Percent change	2012	2014	Percent change	2012	2014	Percent change
Blue grama	13.4	3.1	-76.7%	9.3	7.8	-16.1%	16.5	3.0	-81.2%
Crested wheatgrass	1.9	6.0	+215.8%						
Green needlegrass	11.4	4.8	-57.9%	1.4	1.4	No change	6.9	2.9	-58.0%
Kentucky bluegrass	17.6	28.4	+61.4%	2.7	3.2	+18.5%	35.4	14.7	-58.5%
Little bluestem				8.2	10.9	+32.9%			
Needle-and-thread	3.1	2.4	-22.6%	8.8	8.6	-2.3%	0.4	1.6	+300%
Plains muhly				0.0	1.8	+180.0%			
Prairie sandreed				2.4	0.1	-95.8%			
Sideoats grama				1.3	1.0	-23.1%			
Threadleaf sedge	4.6	2.8	-39.1%	36.7	20.4	-44.4%			
Western wheatgrass	23.3	29.5	+26.6%	13.7	15.0	+9.5%	21.6	30.7	+42.1%

Year effects between 2012 and 2014 on plant community composition at the LMNG were evident within loamy ecological sites at the LMNG (*P* =0.0026). Axis 1 explained 50.6% of the variation and Axis 2 explained 35.0%; overall, 85.6% of the variation was explained by both axes. Threadleaf sedge and western wheatgrass increased by 900.0% and 31.7%; respectively while blue grama (-5.59%), green needlegrass (-12.1%), Kentucky bluegrass (-26.7%), needle-and-thread (-50.0%), and sun sedge (-9.0%) decreased. (Figure 10 and Table 16).

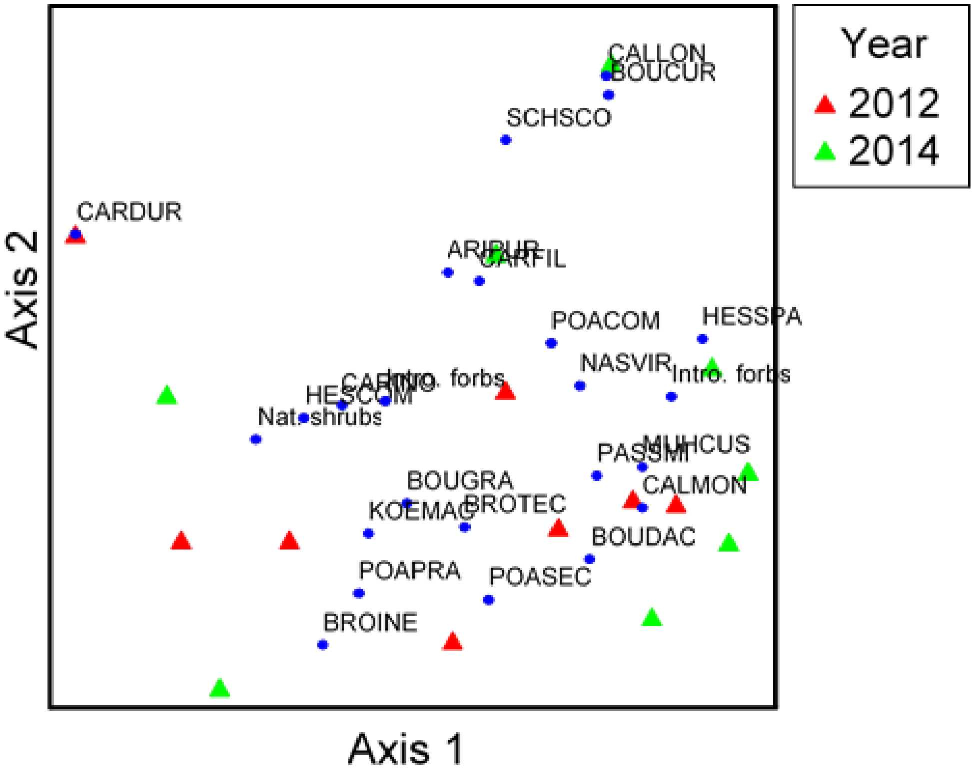


Figure 10. NMS ordination for year effects between 2012 and 2014 on plant community composition on loamy ecological sites at the Little Missouri National Grasslands. Blue dots represent species.

Year effects were also evident on thin loamy ecological sites at the LMNG (*P* =0.0526). Axis 1 and Axis 2 explained 37.4% and 30.3% of the variation; respectively. Overall, 67.7% of the variation was explained by both axes. (Figure 11 and Table 16). Blue grama ,green needlegrass, needle-and-thread, porcupinegrass, sideoats grama, and western wheatgrass increased by 96.1%, 129.4%, 25.0%, 50%, 86.2%, and 115.6%; respectively at the expense of

Kentucky bluegrass (-91.7%), little bluestem (54.1%), plains muhly (-29.6%) and threadleaf sedge (-9.1%; Figure 11 and Table 16).

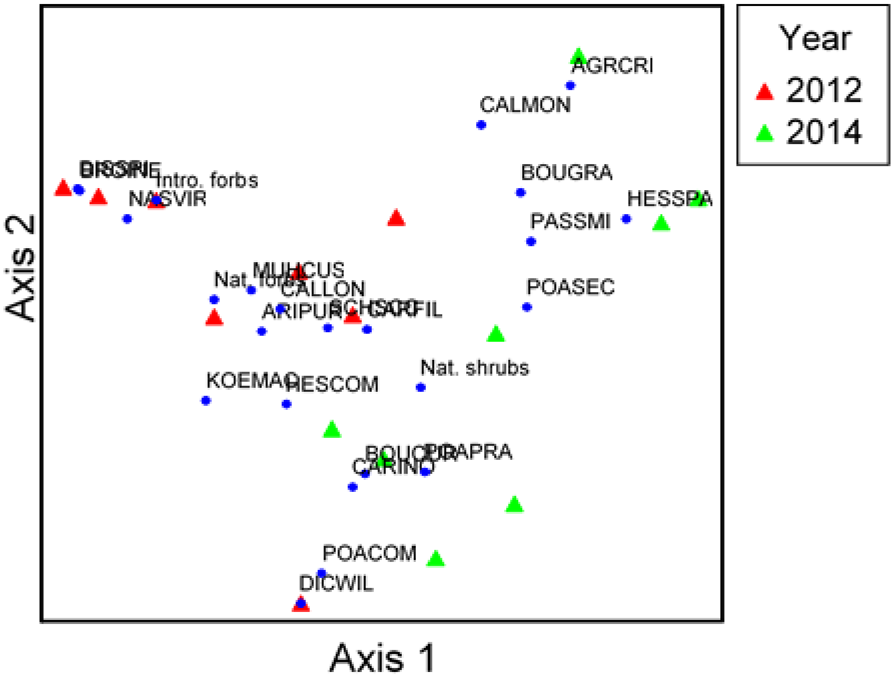


Figure 11. NMS ordination for year effects between 2012 and 2014 on plant community composition on thin loamy ecological sites at the Little Missouri National Grasslands. Blue dots represent species.

Claypan ecological sites at the LMNG also experienced year effects between 2012 and 2014 on plant community composition (*P* = 0.0198). Axis 1 explained 70.4% of the variation and Axis 2 explained 22.0%; overall, 92.4% of the variation was explained by both axes. Western wheatgrass was the only species to increase in abundance (46.0%). Blue grama, green needlegrass, and Kentucky bluegrass, and needle-and-thread decreased by 63.2%, 58.3%, 83.3%, and 60.7%; respectively (Figure 12 and Table 16).

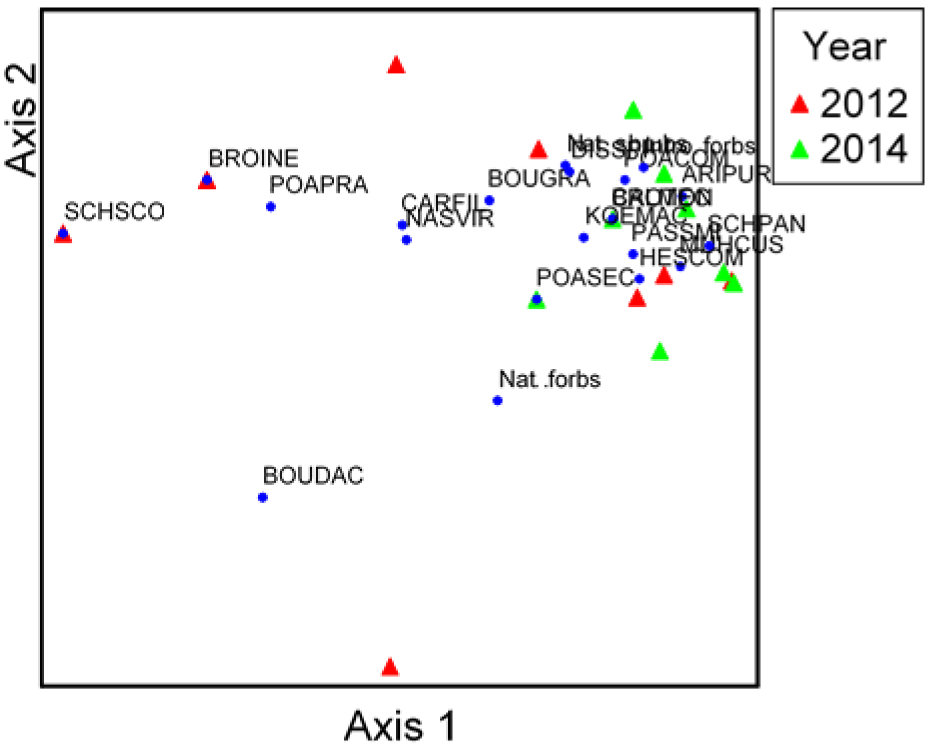


Figure 8. NMS ordination for year effects between 2012 and 2014 on plant community composition on claypan ecological sites at the Little Missouri National Grasslands. Blue dots represent species.

Table 16. Percent change in plant species abundance (phytomass in kg·ha^{-1}) at all ecological sites on the Little Missouri National Grasslands between July 2012 and July 2014.

	Loamy			Thin Loamy			Claypan		
Species	2012	2014	Percent change	2012	2014	Percent change	2012	2014	Percent change
Blue grama	17.9	7.9	-55.9%	5.1	10.0	+96.1%	20.9	7.7	-63.2%
Green needlegrass	6.6	5.8	-12.1%	1.7	3.9	+129.4%	6.0	2.5	-58.3%
Kentucky bluegrass	9.0	6.6	-26.7%	1.2	0.1	-91.7%	6.0	1.0	-83.3%
Little bluestem				22.9	10.5	-54.1%			
Needle-and-thread	9.4	4.7	-50.0%	7.6	9.5	+25.0%	2.8	1.1	-60.7%
Plains muhly				2.7	1.9	-29.6%			
Porcupine-grass				0.1	0.2	+50%			
Sideoats grama				2.9	5.4	+86.2%			
Sun sedge	1.1	1.0	-9.0%						
Threadleaf sedge	0.3	3.0	+900%	9.9	9.0	-9.1%			
Western wheatgrass	33.8	44.5	+31.7%	12.2	26.3	+115.6%	46.1	67.3	+46.0%

Discussion

Standing crop growth characteristics. A significant reduction in standing crop from July to October was evident in 2012 at both the GRNG and LMNG. Reduction in standing crop ranged from 9.3 to 32.6% in 2012. In 2013, claypan sites at the GRNG were the only sites to exhibit a decrease in standing crop (6.0%); loamy sites at the LMNG increased by 5.8% while thin loamy and claypan sites showed virtually no change in standing crop from the summer to fall. In 2014, thin loamy sites were the only ones to show a decrease in standing crop (20.9%). The year to year variability between the July and October standing crop was likely influenced by precipitation, which would have affected growth of warm-season grasses and regrowth of cool-season grasses, as well as vegetation consumption by insects and wildlife grazing. Sedivec et al. (2009 and 2010) stated the disappearance of phytomass occurs naturally once grasses reach peak production in mid-summer, declining due to natural senescence, regardless of whether grazing is present. They found a 30% and 34% disappearance of phytomass from peak production to October for cool-season and warm-season grasses, respectively.

Correlations between standing crop and visual obstruction were variable between individual ecological sites, study locations, and years. However, for those sites with a high ($P \leq 0.05; R^2 \geq 0.60$) correlation between standing crop and visual obstruction, a mean of 2,534 $kg{\cdot}ha^{-1}$ (203.5 SE) of standing crop was needed to achieve high structure (8.89 cm VOR) in the fall. Relationships between standing crop and visual obstruction and the amount of standing crop required to achieve high structure based on regression models have varied among studies, although this is most likely a result of differences in sample size. In this study, a sample size of eight was used in the regressions because of the limited size of the exclosures. Woehl (2010) reported loamy sites on the LMNG and GRNG in 2010 required a minimum of 1,236 $kg{\cdot}ha^{-1}$ and 2,111 $kg.ha^{-1}$ of phytomass to achieve 8.89 cm VOR of high structure. Contrary to the sites we used to determine estimated thresholds of standing crop to achieve 8.89 cm, Woehl's (2010) study reported thresholds using poor correlations and only addressed phytomass (versus standing crop in our study). Vader (2000) studied ecological sites on the LMNG and found a strong relationship ($R^2 = 0.69$) in VOR to standing crop on the loamy sites. Using Vader's (2000) models, the loamy sites on the LMNG would require 1,764 $kg{\cdot}ha^{-1}$ of standing crop to produce 8.89 cm VOR (Table 17). Vader found a poor relationship between VOR and standing crop on the loamy overflow and thin upland ecological sites. However, strong relationships ($R^2 \geq$

0.60) were reported between VOR and standing crop in Wyoming (Uresk and Juntti 2008), Oklahoma (Vermeire and Gillen 2001), and Texas (Vermeire et al. 2002) (Table 17).

Table 17. Studies from the Great Plains that developed models to predict standing crop/phytomass from visual obstruction readings on loamy ecological sites.

Study	**Location**	**Model**	**R^2 (0 – 1)**	**X $lb \cdot ac^{-1}$ =3.5 in**	**X $kg \cdot ha^{-1}$ = 8.89 cm**
Woehl 2010[1]	GRNG	$Y = 1.689X + 22.69$	0.42	1,885	2,111
Woehl 2010[1]	LMNG: McKenzie Ranger District	$Y = 0.577X + 20.08$	0.02	1,261	1,412
Woehl 2010[1]	LMNG: Medora Ranger District	$Y = 0.925X + 13.86$	0.27	1,104	1,236
Vader 2000[2]	LMNG	$Y = 1374.8X + 547$	0.69	1,575	1,764
Uresk and Benzon 2007[2]	Black Hills, SD	$Y = 848.0X + 114$		1,466	1,642
Uresk and Juntti 2008[2]	Big Horn, WY	$Y = 650.1X + 189$	0.81	1,755	1,966
Vermeire and Gillen 2001[3]	Stillwater, OK	$Y = 116X + 149$	0.79	1,051	1,177
Vermeire and Gillen 2001[3]	Stillwater, OK	$Y = 169X + 494$	0.64	1,778	1,991
Vermeire et al. 2002[2]	Texas		0.89	1,750	1,960

[1] Models were developed from phytomass collections
[2] Models were developed from standing crop collections
[3] Models were developed from collecting only one cardinal direction of the Robel pole

Coefficients of determination on sandy sites were almost always lower than loamy sites, Coefficients of determination on sandy sites at the GRNG, LMNG, and Sheyenne National Grasslands (SNG) of the DPG were rarely over 0.50, and required 1,679 to 3,291 $kg \cdot ha^{-1}$ of phytomass (Woehl 2010) or standing crop (Vader 2000) to produce an 8.89 cm VOR (Table 18). In Nebraska, Benkobi et al. (2000) found a strong relationship ($R^2 = 0.88$) between standing crop and VOR on sandy sites, requiring 2,184 $kg \cdot ha^{-1}$ of standing crop to achieve an 8.89 cm VOR. However, Volesky et al. (1999) found a weak coefficient of determination on the Nebraska

Sandhills, $R^2 = 0.41$, and required 1,696 kg·ha^{-1} of standing crop to produce an 8.89 cm VOR (Table 18).

Table 18. Studies from the Great Plains that developed models to predict standing crop/phytomass from visual obstruction readings on sandy ecological sites.

Study	**Location**	**Model**	**R^2 (0 – 1)**	**X lb·ac^{-1} = 3.5 in**	**X kg·ha^{-1} = 8.89 cm**
Woehl 2010[1]	GRNG	$Y = 2.893X + 16.30$	0.39	2,102	2,354
Woehl 2010[1]	LMNG – McKenzie Ranger District	$Y = 0.773X + 23.11$	0.02	1,500	1,680
Woehl 2010[1]	LMNG – Medora Ranger District	$Y = 0.773X + 23.10$	0.11	1,499	1,679
Vader 2000[2]	SNG – Upl.	$Y = 2381.3X – 69$	0.49	2,147	2,405
Vader 2000[2]	SNG – Mid	$Y = 2246.2X + 516$	0.70	2,238	2,507
Vader 2000[2]	SNG – Low	$Y = 610.5X + 2440$	0.34	2,983	3,291
Benkobi et al. 2000[2]	Nebraska – Low	$Y = 241.8X + 39.1$	0.88	1,950	2,184
Volesky et al. 1999[2]	Nebraska, Sandhills	$Y = 14.98X + 36.5$	0.41	1,514	1,696

[1] Models were developed from phytomass collections

[2] Models were developed from standing crop collections

Coefficients of determination also varied between other ecological sites. Claypan sites at the GRNG were lower ($R^2 = 0.44$; Woehl 2010) than other studies ($R^2 = 0.82$; Uresk 2012) (Table 20). Relationships also differed in strength between shallow, overflow, (Vader 2000) and shallow claypan/overflow sites (Uresk 2012) (Table 19).

Table 19. Studies that created models to predict production from visual obstruction on other ecological sites in the Great Plains.

Study	Location		Model	R^2 (0 – 1)	X $lb \cdot ac^{-1}$ = 3.5 in	X $kg \cdot ha^{-1}$ = 8.89 cm
Woehl 2010[1]	GRNG	Claypan	$Y = 1.272X + 24.67$	0.44	1,801	2,017
Uresk 2012[2]	South Dakota	Claypan	$Y = 517.6 + 524.8X$	0.82	2,096	2,348
Vader 2000[2]	LMNG	Shallow	$Y = 1185.1X + 536$	0.37	1,415	1,585
Vader 2000[2]	LMNG	Overflow	$Y = 988.5X + 1756$	0.61	2,346	2,628
Uresk 2012[2]	South Dakota	Shallow claypan/ Overflow	$Y = 863.4 + 555.5X$	0.79	2,499	2,799

[1] Models were developed from phytomass collections

[2] Models were developed from standing crop collections

Biological capability. The biological capability of the selected ecological sites loamy, thin loamy, and claypan to produce high structure VOR of 8.89 cm (3.5 in) at the end of the growing season (October 15; USDA, Forest Service 2001) was determined at two locations within the DPG. Claypan sites at the GRNG and loamy sites at the LMNG were the only sites to achieve high structure in October every year. However, all selected ecological sites were biologically capable of producing high structure in the fall after three years of exclusion from livestock grazing.

The ability of ecological sites to achieve high structure VOR of 8.89 is affected by their environment, species composition, past grazing management, precipitation, presence/absence of grazing ungulates, and litter accumulation. Above-average precipitation was received at the GRNG in 2011, 2013, and 2014, 108%, 181%, and 106%; respectively, while below-average precipitation was received in 2012; 90%. At the LMNG, nearly similar patterns were observed with the area receiving 135% and 131% of average precipitation in 2011 and 2013; respectively, while, 2012 and 2014 were less than normal (72% and 91%; respectively). Studies in the Northern Great Plains have shown a positive relationship ($P < 0.01$; $R^2 = 0.90$; Sala et al. 1988) between precipitation and forage production (Smoliak 1986; Heitschmidt et al. 2005). Patton et al. (2007) found that phytomass was higher on grazed treatments than un-grazed treatments when precipitation exceeded 250 mm from the end of the growing season in the previous year to the end of the growing season in the current year on overflow sites in south-central North Dakota. Although 2012 and 2014 were considered drier than average, both 2011 and 2013 received above average fall moisture, providing more moisture for plant growth each of the subsequent years 2012 and 2014. In particular, 2013 growing season moisture was 129 % and 164 % of the long-term average on the LMNG and GRNG, respectively.

Litter accumulation, as a result of protection from grazing, can directly and indirectly effect the landscape. Protection from grazing affects net primary production, standing litter, and standing crop (Milchunas and Lauenroth 1993), with protection resulting in greater phytomass yields (Willms et al. 2002). Soil moisture retention improves as litter accumulates; however, a lack of grazing may be detrimental to species diversity even though it has been recognized as a means to improve range condition under certain circumstances (Milchunas and Lauenroth 1993).

Biological capability has been proven achievable on all selected ecological sites. However, can these ecological sites achieve biological capability under grazing conditions and with average precipitation conditions? Kirsch et al. (1973) recommended that grazing be suspended on rangelands managed for prairie grouse habitat; however, his comments were related to a time period when exotic cool-season grasses were minimal on rangelands of the Northern Plains. Woehl (2010) reported mean VORs of 6.0 cm (2.36 in), 5.73 cm (2.25 in), and 5.19 cm (2.04 in) on loamy, clayey, and sandy ecological sites; respectively, on the GRNG and

LMNG during peak production from 2007 to 2009 with none to slight grazing pressure. Vader (2000) reported mean VORs of 6.02 cm (2.37 in), 6.5 cm (2.56 in), and 24.06 cm (9.47 in) on shallow, loamy, and loamy overflow sites; respectively, during peak production at the LMNG with light to no grazing pressure. However, Reece et al. (2001) reported that even though visual obstruction decreases with increasing cumulative grazing pressure, high structure may be maintained on grazed rangelands during peak production when cumulative grazing pressure was low. Evans (1968) suggested that light to moderate stocking rates are capable of leaving adequate residual cover for nesting sharp-tailed grouse. Kirby and Grosz (1995) also support the use of grazing systems utilized with a 50 percent degree of disappearance on lands in the Northern Great Plains for sharp-tailed grouse production. High structure was capable with rotational grazing systems, even though less than 20% of grazed pastures had a VOR greater than 10.16 cm (4 inches) (Kirby and Grosz 1995).

Plant community. Variation in plant community composition occurred as a result of year effects and study location on ecological sites. Year effects occurred at the GRNG ($P = 0.0062$) and LMNG ($P = 0.0358$) within all ecological sites; more than 70% of the variation was explained by both axes in each ordination. Plant community variability also differed ($P = 0.0002$) between locations at each ecological site. More than 70% of the variation was also explained by both axes in ordinations for each ecological site. Strength of the relationships in year to year variability also differed between each ecological site at their respective locations. Sites that were significant at the 0.10 significance level included loamy ($P = 0.0946$) and claypan ($P = 0.0110$) ecological sites at the GRNG and thin loamy ($P =0.0004$) and claypan ($P = 0.0604$) ecological sites at the LMNG.

Plant species abundances changed after three years of protection of livestock grazing on the GRNG and LMNG. On the GRNG, western wheatgrass was the only species to increase on all selected ecological sites, while blue grama was the only species to decrease at all selected ecological sites. However, western wheatgrass and Kentucky bluegrass tended to both increase at the expense of warm-season grasses on loamy and thin loamy ecological sites. At the LMNG, western wheatgrass increased on all selected ecological sites while Kentucky bluegrass decreased at all ecological sites.

Western wheatgrass tended to increase with three years of livestock grazing protection at the expense of warm-season grasses on the GRNG and LMNG. These results were supported by other studies within the mixed-grass prairie. Vogel and Van Dyne (1966) measured vegetative responses to grazing management practices between 1953 and 1957 and found that bluegrass species (*Poa cusickii* and *Poa secunda*) increased in cover on rangelands protected from grazing. In southeastern Alberta, protection from livestock grazing resulted in increased western wheatgrass while blue grama and sandberg bluegrass decreased (Willms et al. 2002).

Murphy and Grant (2005) and DeKeyser et al. (2009) found species composition changed under non-use management practices on central North Dakota rangelands. The Des Lacs and J. Clark Salyer National Wildlife Refuges (NWRs) (Murphy and Grant 2005) and Knife River Indian Villages National Historic Site (DeKeyser et al. 2009) deteriorated through invasion of introduced, cool-season grasses smooth brome and Kentucky bluegrass. These invasions were considered an unforeseen result of protection from livestock grazing.

Biondini et al. (1998) reported species compositional changes at the Central Grasslands Research Center located near the eastern edge of the Missouri Coteau in North Dakota. Kentucky bluegrass and western wheatgrass increased in relative basal cover between 1988 and 1993 from

35 to 54% and 6 to 10%; respectively, while blue grama and needlegrass species decreased from 24 to 8% and 12 to 6%; respectively under non-use management. They concluded that major trends in vegetation are driven by climatic variations, especially drought. These conclusions were supported by Whitman et al. (1943) who reported drought was the primary mechanism responsible for significant vegetation changes in the mixed-grass prairie.

Biondini and Manske (1996) found evidence supporting to our findings regarding impacts of non-use on blue grama. Blue grama usually decreased in abundance with no livestock grazing; they also reported a decline in blue grama composition with no livestock grazing near Dickinson, North Dakota. They stated their findings were consistent with its characterization as an increaser species. However, our findings are not supported by Heitschmidt and Vermeire (2006), where a shift from cool- to warm-season perennial grasses occurred as a result of greater amounts of summer precipitation than spring precipitation.

Summary/Conclusion

For many years, the Robel pole (Robel et al. 1970) has been used by the USFS and United State Fish and Wildlife Service as the favored method to assess visual obstruction by the USFS to assess sharp-tailed grouse habitat quality at the end of the grazing season. In addition to assessing habitat quality, the USFS also uses VOR as an assessment tool to help in determining if management, including stocking rate, rotations, and timing is providing the desired herbaceous structure distribution. (USDA, Forest Service 2001). Our study hypotheses were 1) there is a correlation and relationship between standing crop and visual obstruction on three selected ecological sites (loamy, thin loamy, and claypan), 2) these selected ecological sites in this study are biologically capable of producing high structure (8.89 cm VOR), 3) the US Forest Service's expectations that all ecological sites are capable of achieving high structure if they produce at least 1,232 kg·ha^{-1}, and 4) no plant community composition changes will occur after three years of no livestock grazing.

We rejected the hypothesis that reliable correlations and relationships exist between standing crop and visual obstruction on the loamy, thin loamy and claypan ecological sites. Due to environmental drivers, correlations between standing crop and visual obstruction were inconsistent between individual ecological sites, study locations, and years. In addition, strong relationships ($R^2 \geq 0.60$) did not always exist in models that exhibited a significant correlation ($P \leq 0.05$).

We failed to reject the hypothesis that all selected ecological sites were biologically capable of achieving high structure (8.89 cm VOR). Claypan sites at the GRNG and loamy sites at the LMNG were capable of producing at least 8.89 cm VOR during each year of the study. After three years of no livestock grazing and excess moisture in 2011 and 2013, all ecological sites were capable of producing 8.89 cm VOR. We attributed these results to excess available moisture from above-average precipitation, protection from grazing, and litter accumulation.

Results from this study did not support the Forest Service's assumption that if a site can produce 1,232 kg·ha^{-1}, it should be biologically capable of producing high structure. According to our models, this standing crop threshold would produce a minimum of 4.69 cm VOR. Therefore, we reject the Forest Service's assumption. We suggest an average of 2,534 kg·ha^{-1} (2,328.7 to 2739.3 kg·ha^{-1}) be used as the standing crop threshold to determine if loamy, thin loamy, or claypan ecological sites will be biologically capable of producing high structure.

In regards to the plant communities, study location and year effects were evident on ecological sites at both the GRNG and LMNG, thus rejecting our hypothesis no change in plant species composition will occur after three years of no livestock grazing. Differences (P =

0.0002) occurred between the GRNG and LMNG within each ecological site and year effects were evident on the loamy and claypan sites at the GRNG and thin loamy and claypan sites at the LMNG. At the GRNG and LMNG, western wheatgrass tended to increase with three years of protection from livestock grazing at the expense of warm-season grasses.

Management Implications

The modified Robel pole did not serve as a consistent means to estimate standing crop from VOR on the loamy, thin loamy and claypan ecological sites across multiple years. However, all selected ecological sites were biologically capable of producing high structure visual obstruction and capable of producing adequate cover for sharp-tailed grouse at the end of the grazing season. Our models showed 1,232 $kg \cdot ha^{-1}$ is not a reliable threshold of standing crop production to assume ecological sites are biologically capable of producing high structure. We suggest an average of 2,534 $kg \cdot ha^{-1}$ be used as the amount of standing crop production to define the ability of ecological sites to attain high structure.

In order to attain the Geographic Area objectives set by the USFS to maintain healthy plant communities with a full spectrum of warm and cool-season species, manage for vegetation structure through the adoption of grazing management and stocking rate guidelines, and control the spread of invasive and non-native species, we recommend the application of light to moderate grazing intensities. With the natural occurrence of senescence, effective grazing must occur before the onset of senescence. Application of these techniques will help maintain the desired structural mosaic on the landscape, sustain high structure grasslands for sharp-tailed grouse habitat, and support rangeland health.

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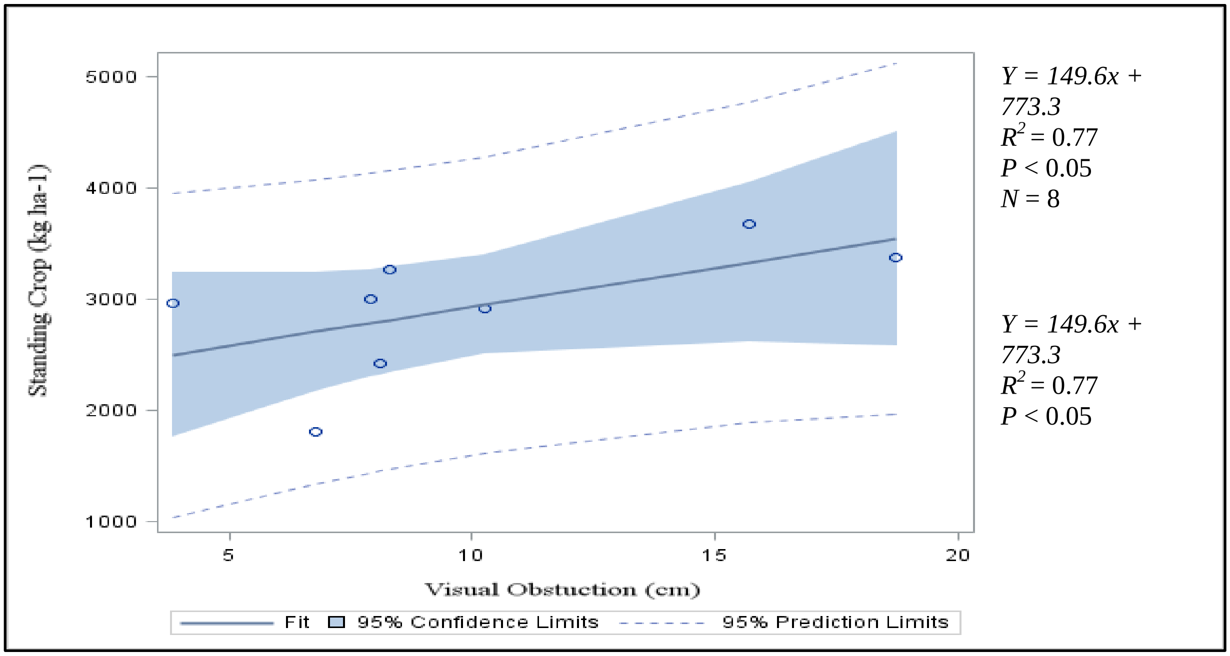
APPENDIX A. LINEAR REGRESSION MODELS COMPARING VISUAL OBSTRUCTION AND STANDING CROP BY ECOLOGICAL SITE AT THE GRAND RIVER NATIONAL GRASSLAND AND LITTLE MISSOURI NATIONAL GRASSLAND STUDY LOCATION



$Y = 149.6x + 773.3$
$R^2 = 0.77$
$P < 0.05$
$N = 8$

$Y = 149.6x + 773.3$
$R^2 = 0.77$
$P < 0.05$

Figure A 1. Linear regression model for loamy ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2012.

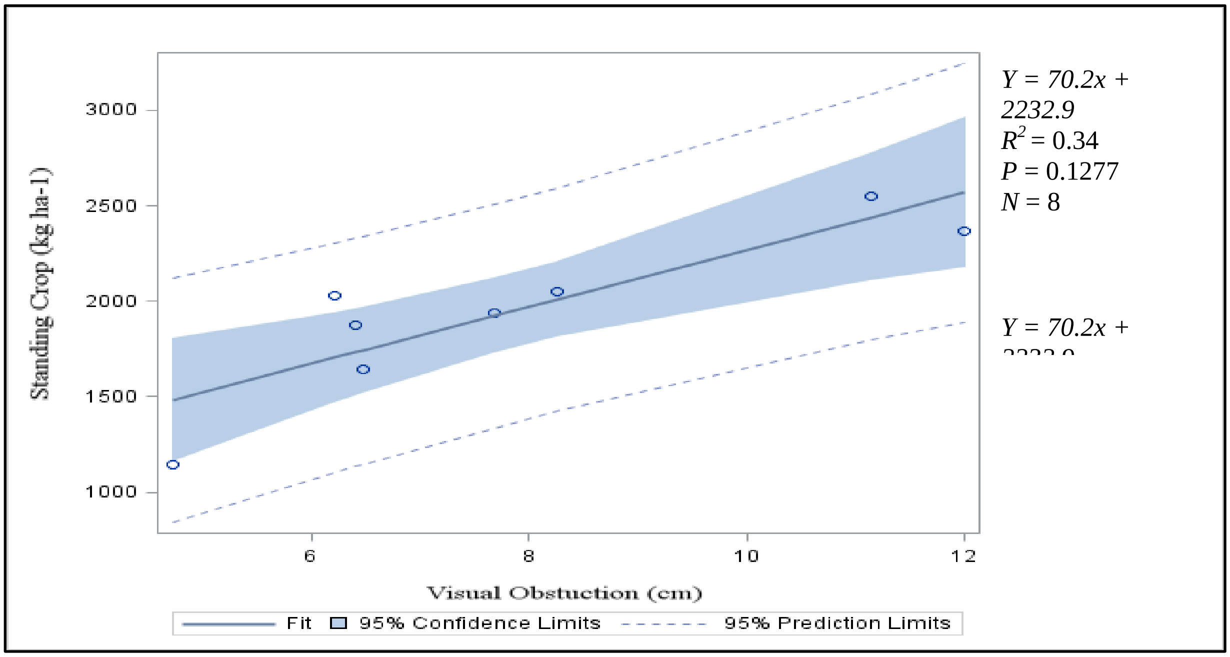


Figure A 2. Linear regression model for thin loamy ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2012.

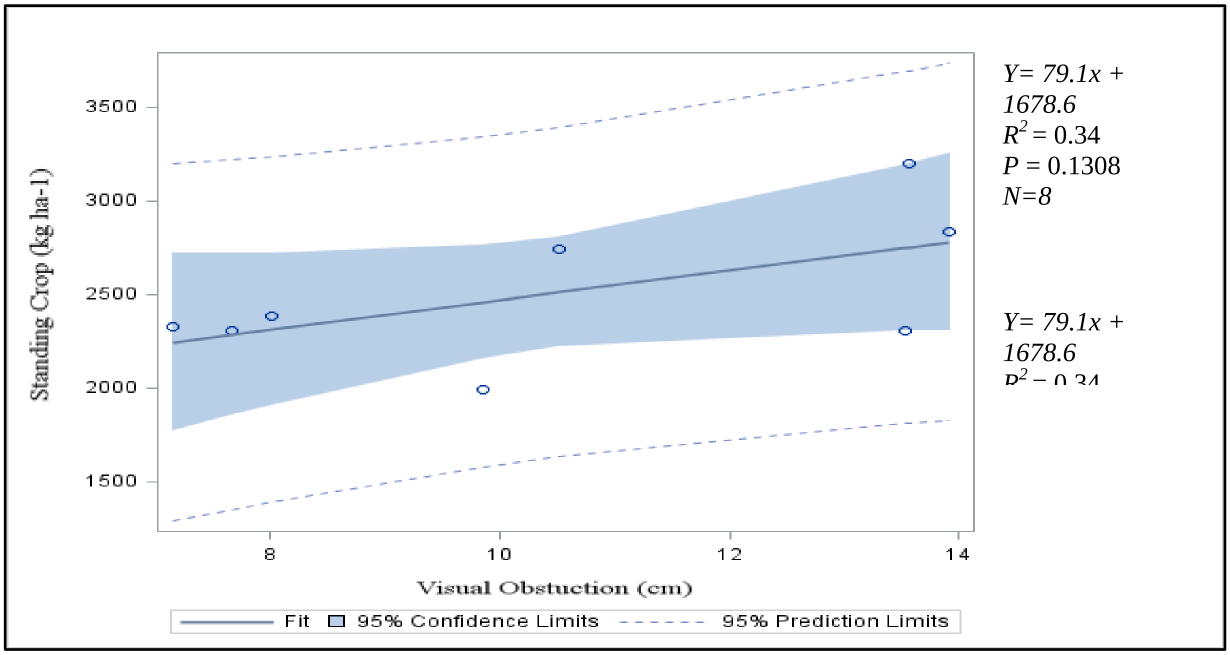
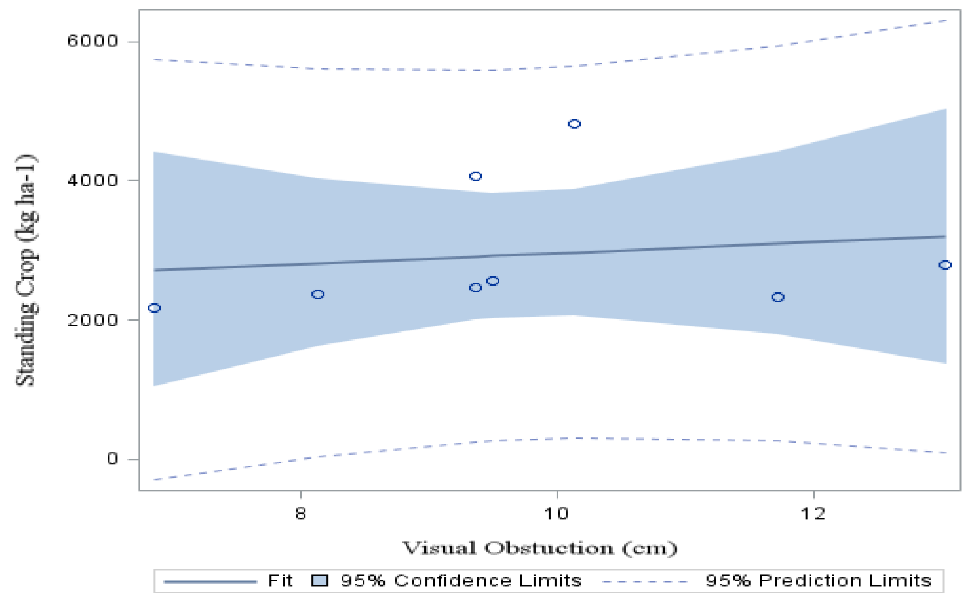


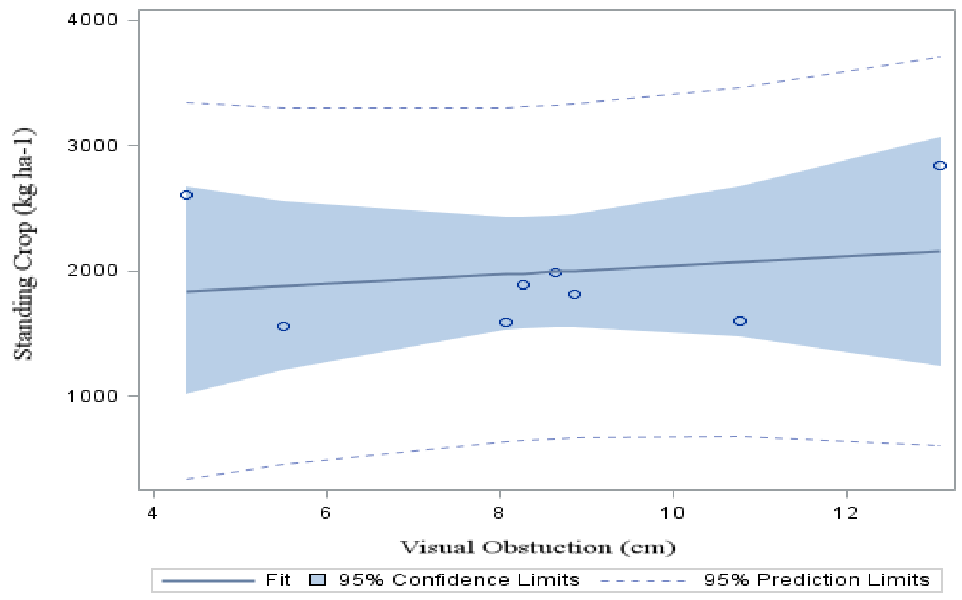
Figure A 3. Linear regression model for claypan ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2012.



Y= 76.7*x* + 2199.1
$R^2 = 0.0237$
P = 0.7159
N=8

Y= 76.7*x* + 2199.1

Figure A 4. Linear regression model for loamy ecological sites at the Little Missouri National Grasslands with associated linear regression model, 95% confidence interval, and prediction limits for July 2012.



Y= 36.1*x* + 1683.2
$R^2 = 0.0416$
$P \leq 0.6282$
N=8

Y= 36.1*x* + 1683.2

Figure A 5. Linear regression model for thin loamy ecological sites at the Little Missouri National Grasslands with associated linear regression model, 95% confidence, and prediction limits for July, 2012.

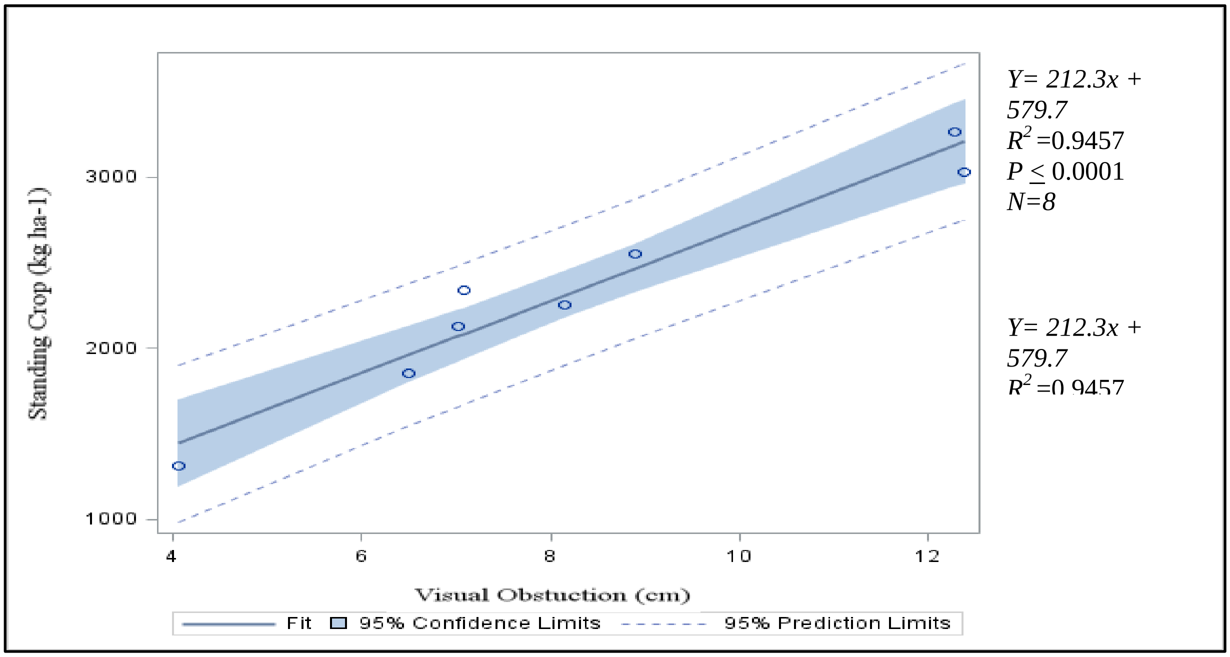


Figure A 6. Linear regression model for claypan ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2012.

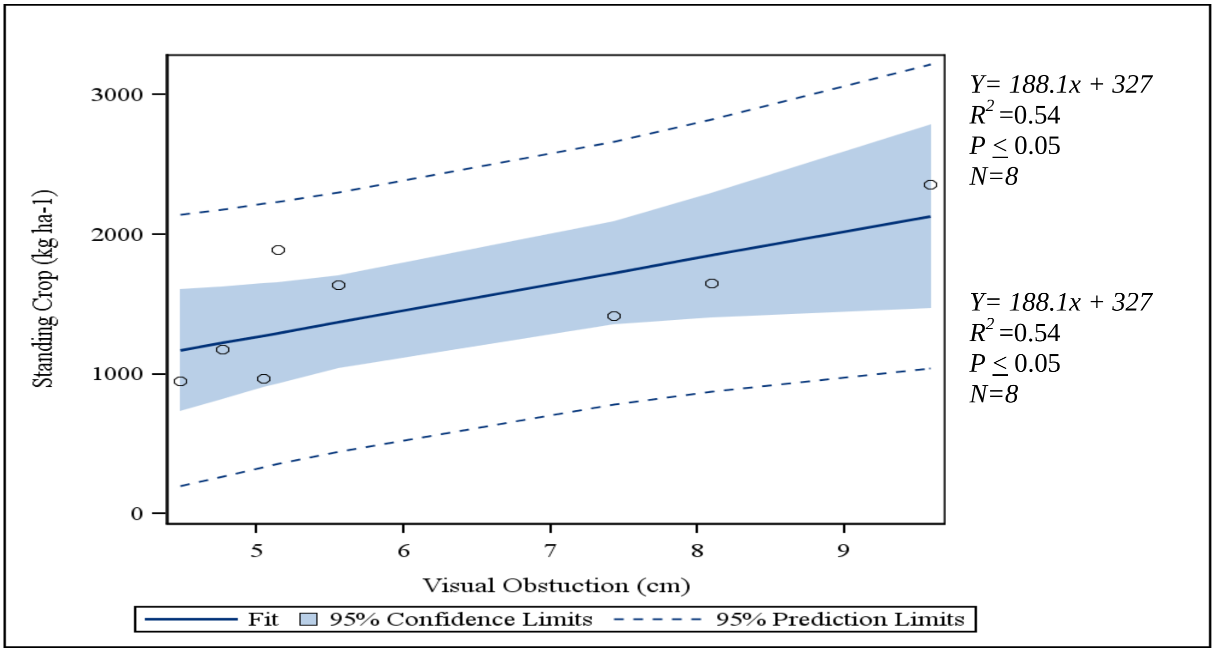


Figure A 7. Linear regression model for thin loamy ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2012.

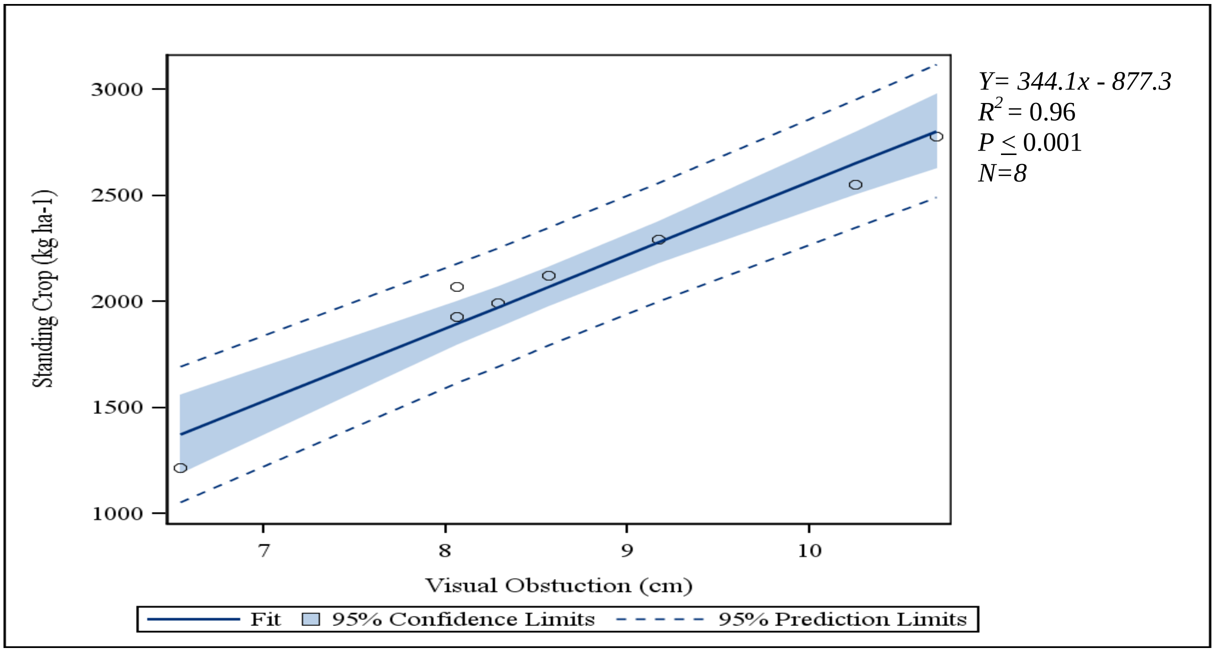


Figure A 8. Linear regression model for claypan ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2012.

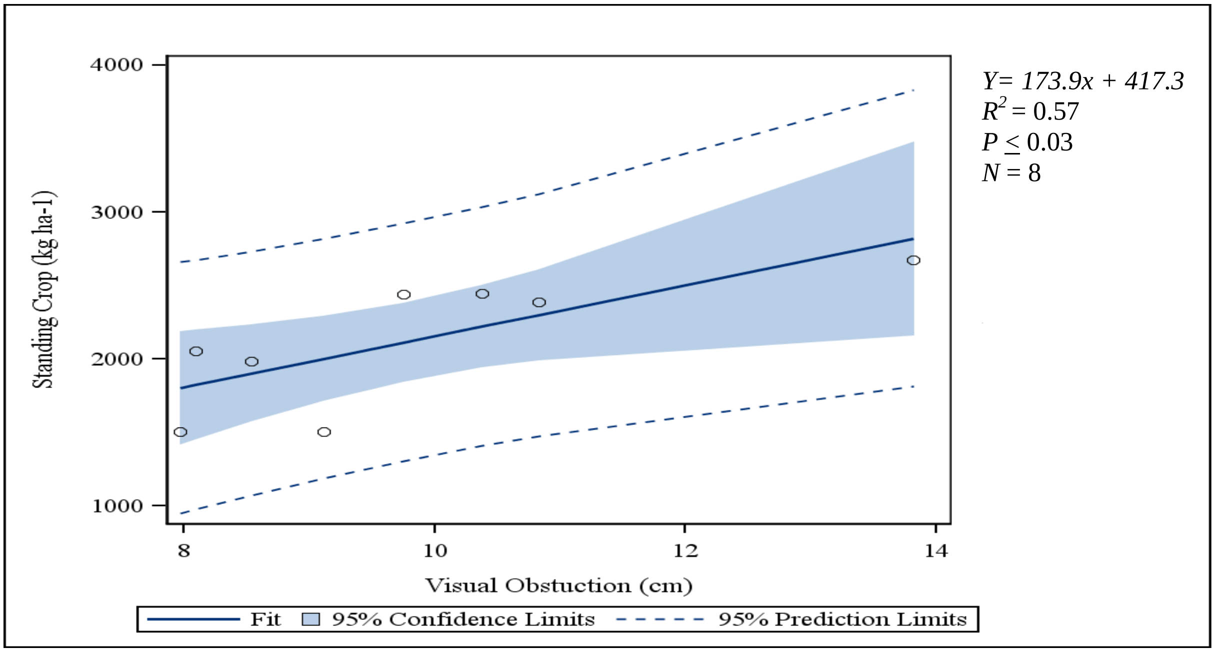


Figure A 9. Linear regression model for loamy ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2012.

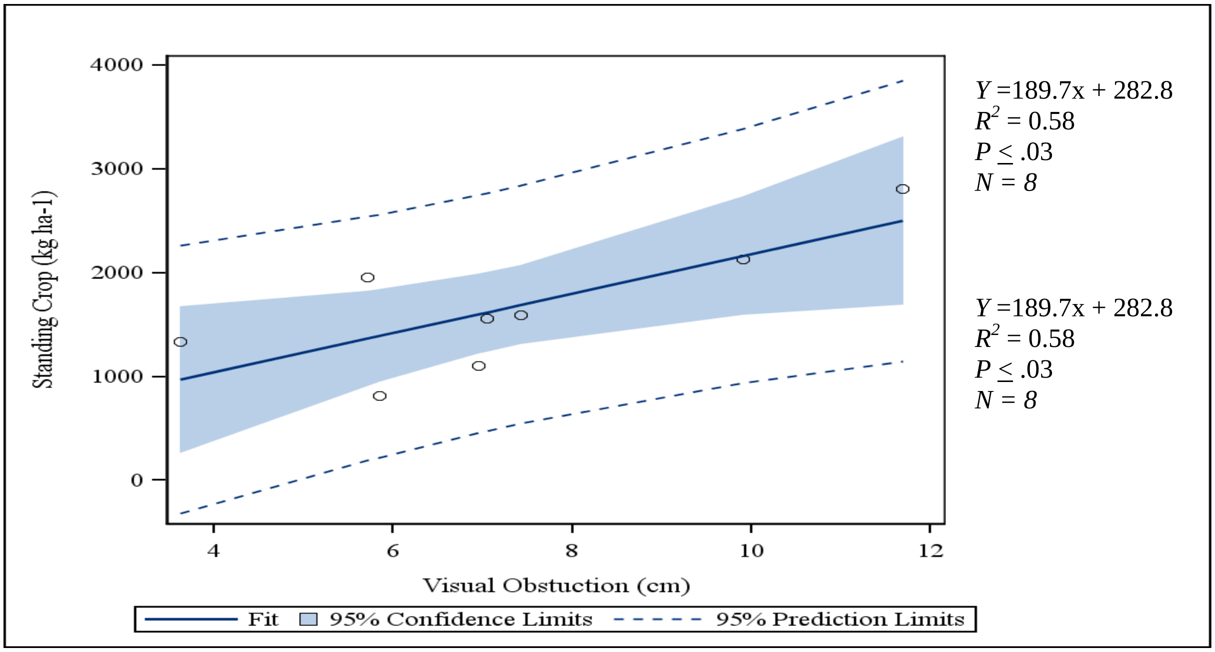


Figure A 10. Linear regression model for thin loamy ecological sites at the Little Missouri National Grasslands with associate regression model, 95% confidence, and prediction limits for October, 2012.

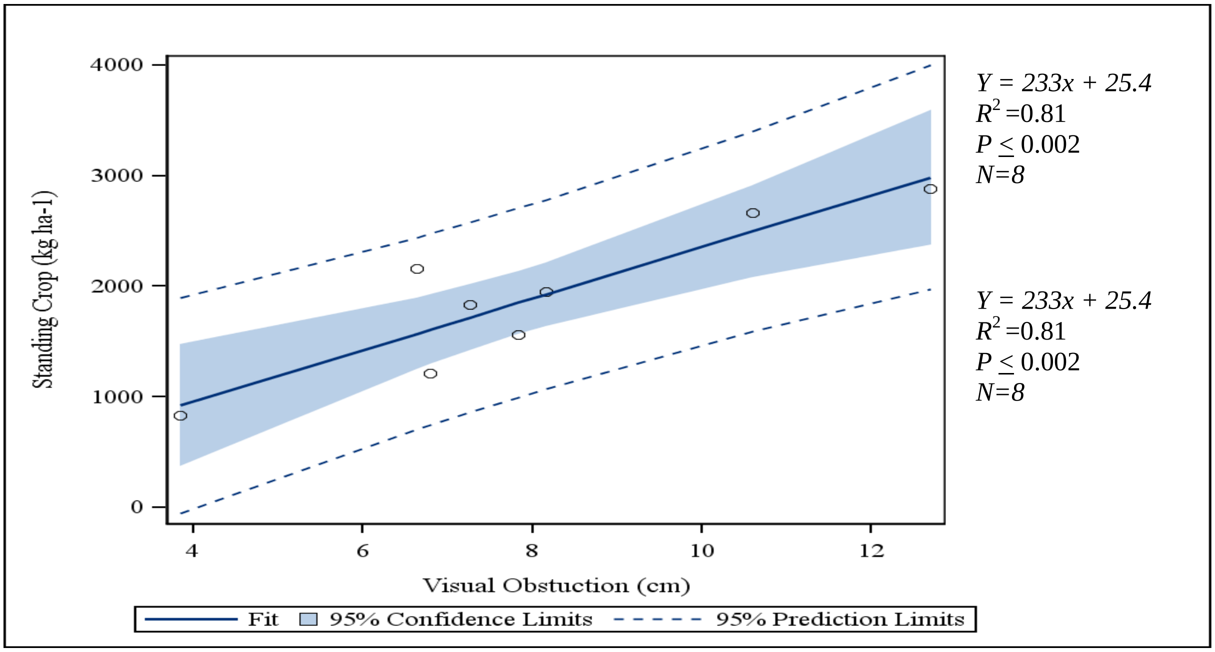


Figure A 11. Linear regression model for claypan ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2012.

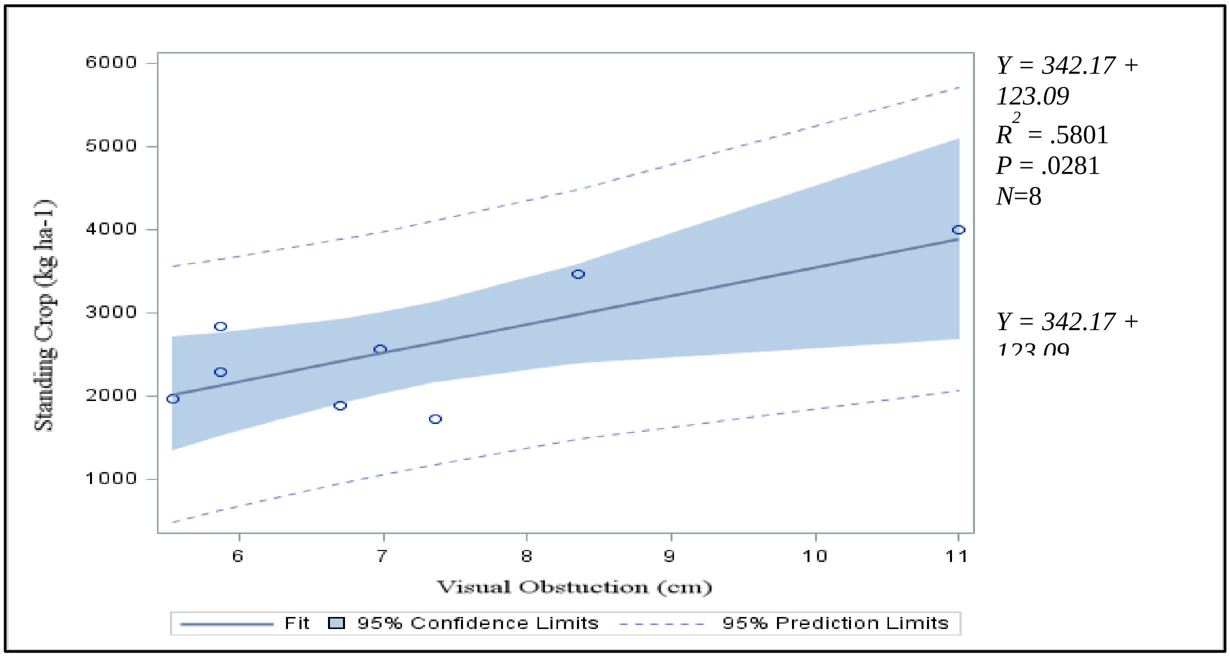


Figure A 12. Linear regression model for claypan ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2013.

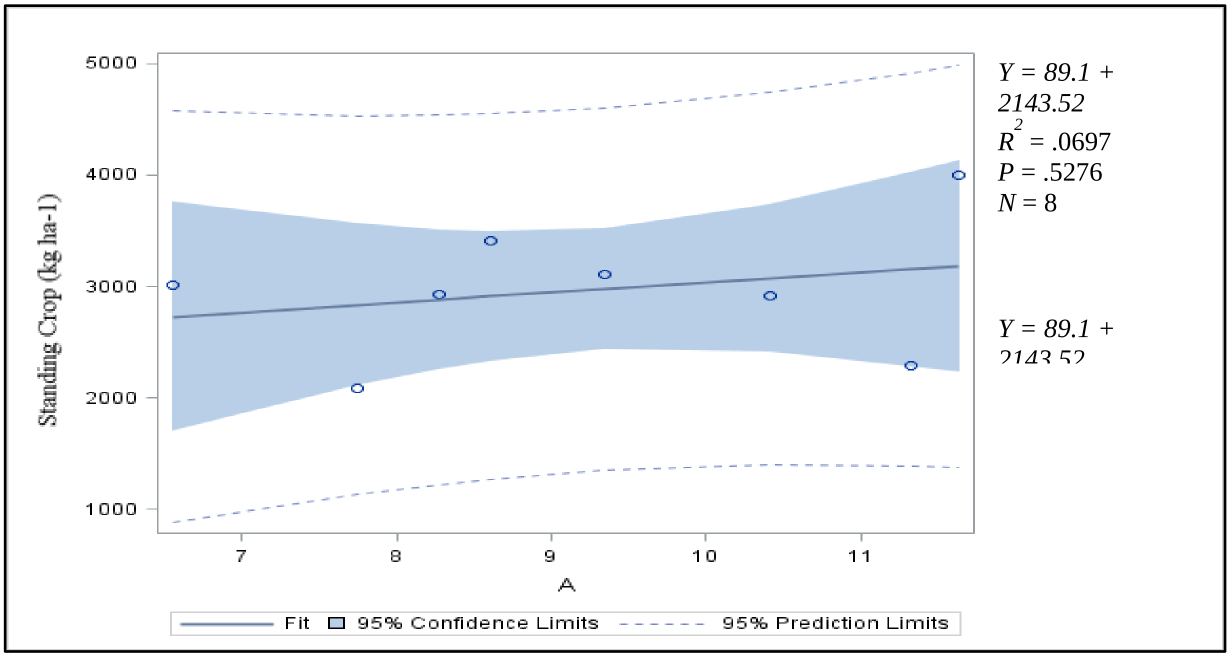


Figure A 13. Linear regression model for loamy ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2013.

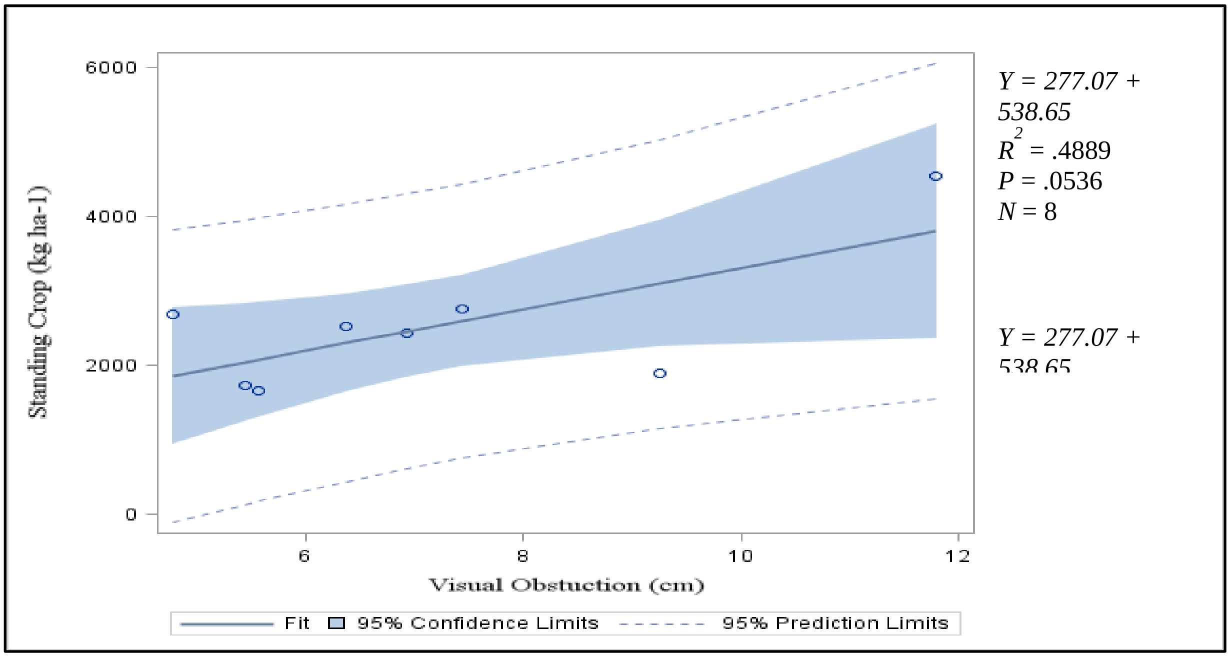


Figure A 14. Linear regression model for claypan ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2013.

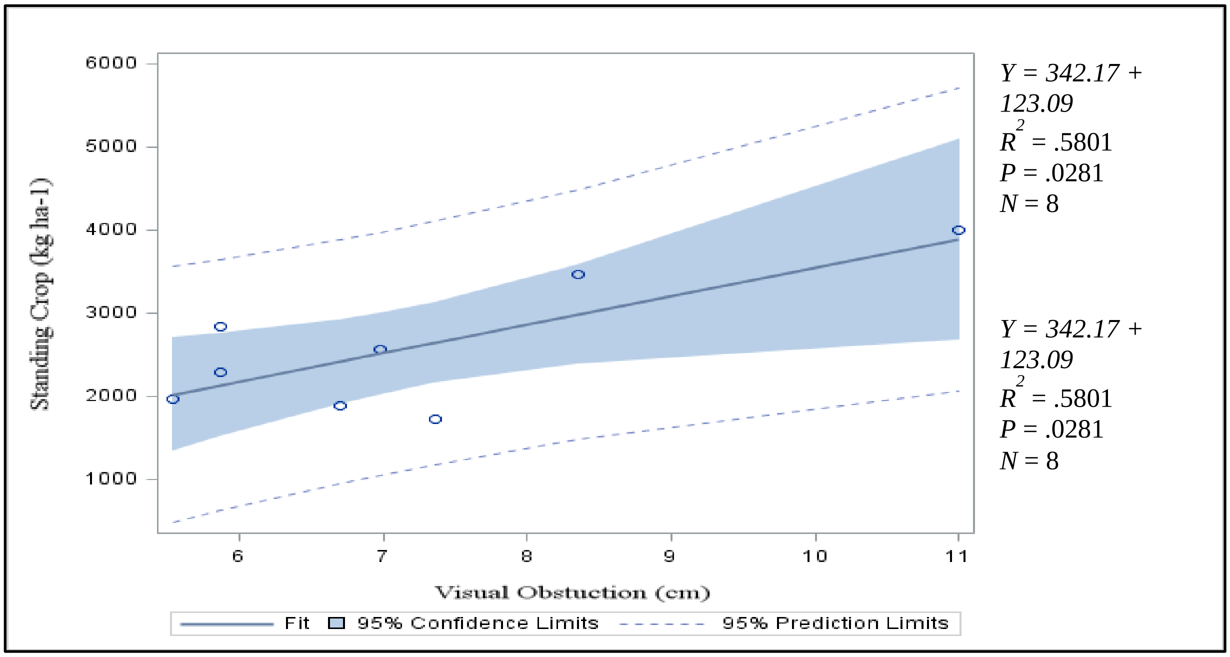


Figure A 15. Linear regression model for claypan ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2013.

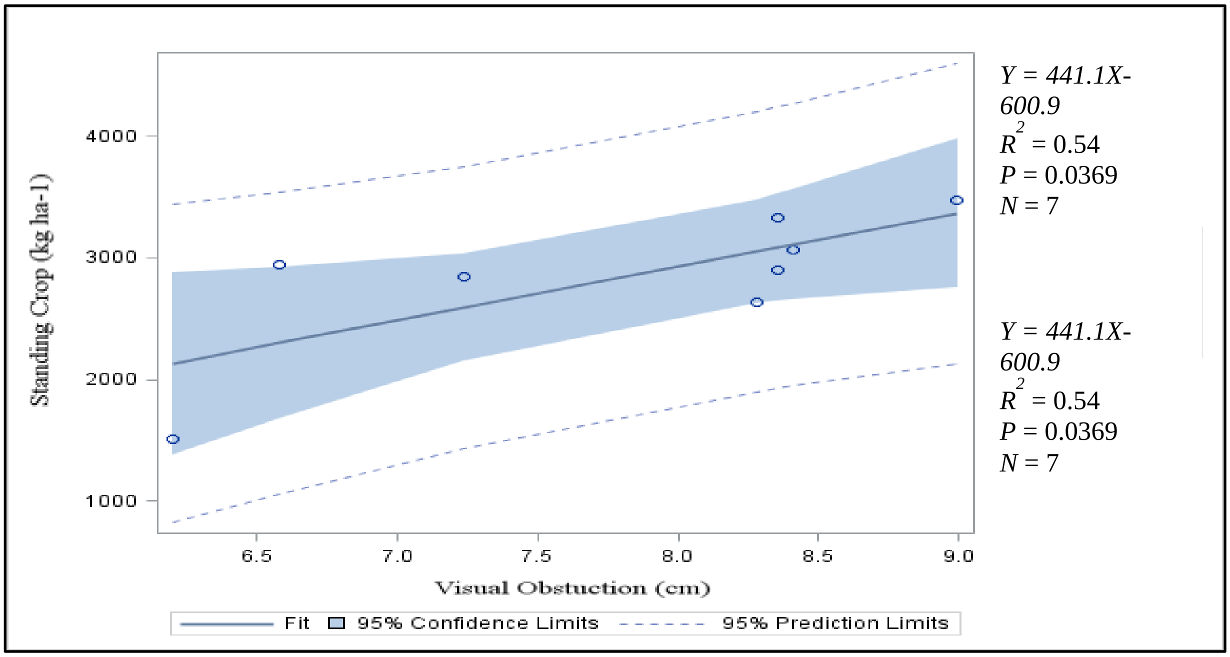


Figure A 16. Linear regression model for loamy ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2013.

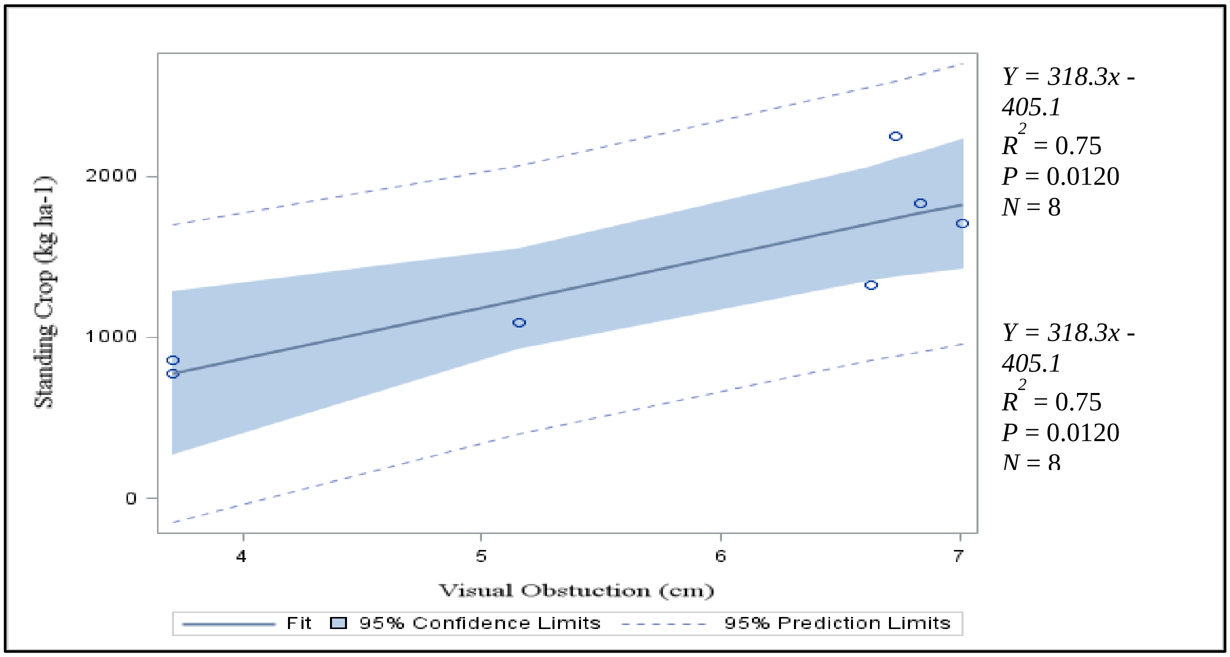


Figure A 17. Linear regression model for thin loamy ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2013.

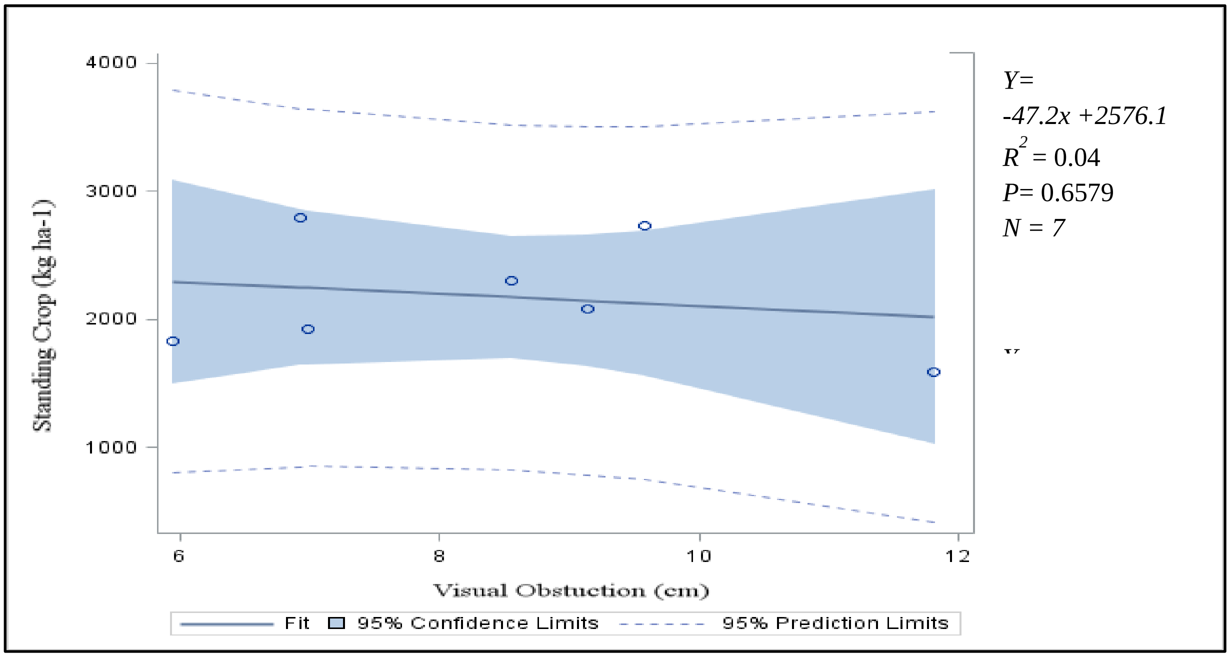


Figure A 18. Linear regression model for claypan ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2013.

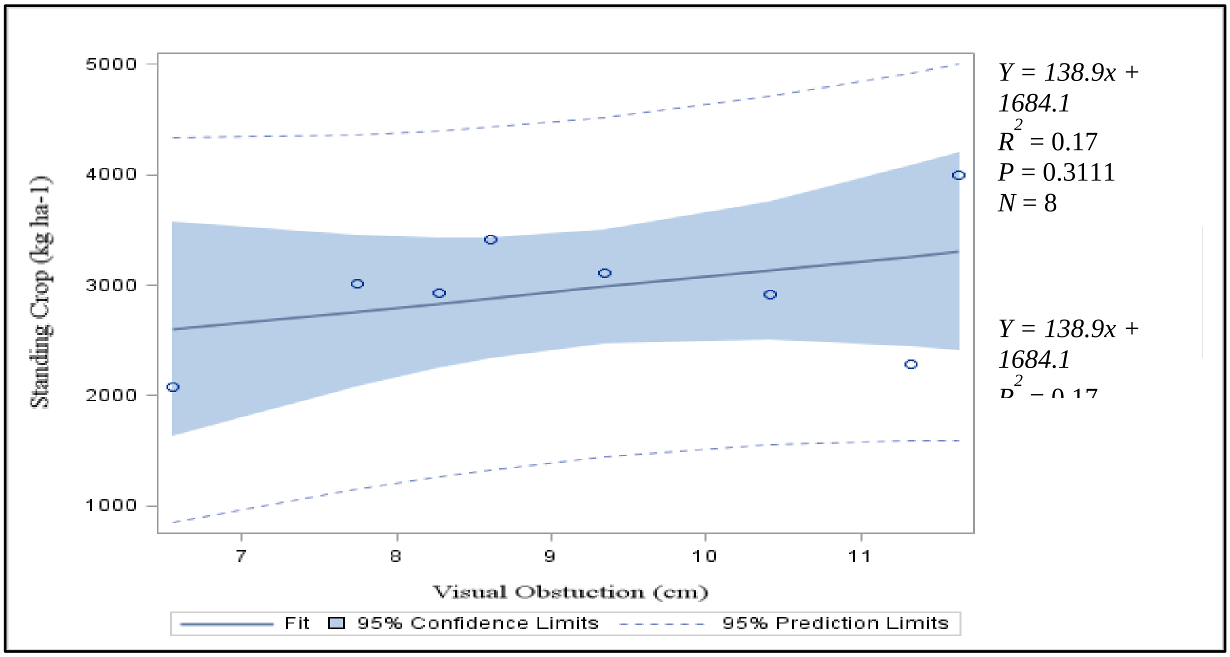


Figure A 19. Linear regression model for loamy ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2013.

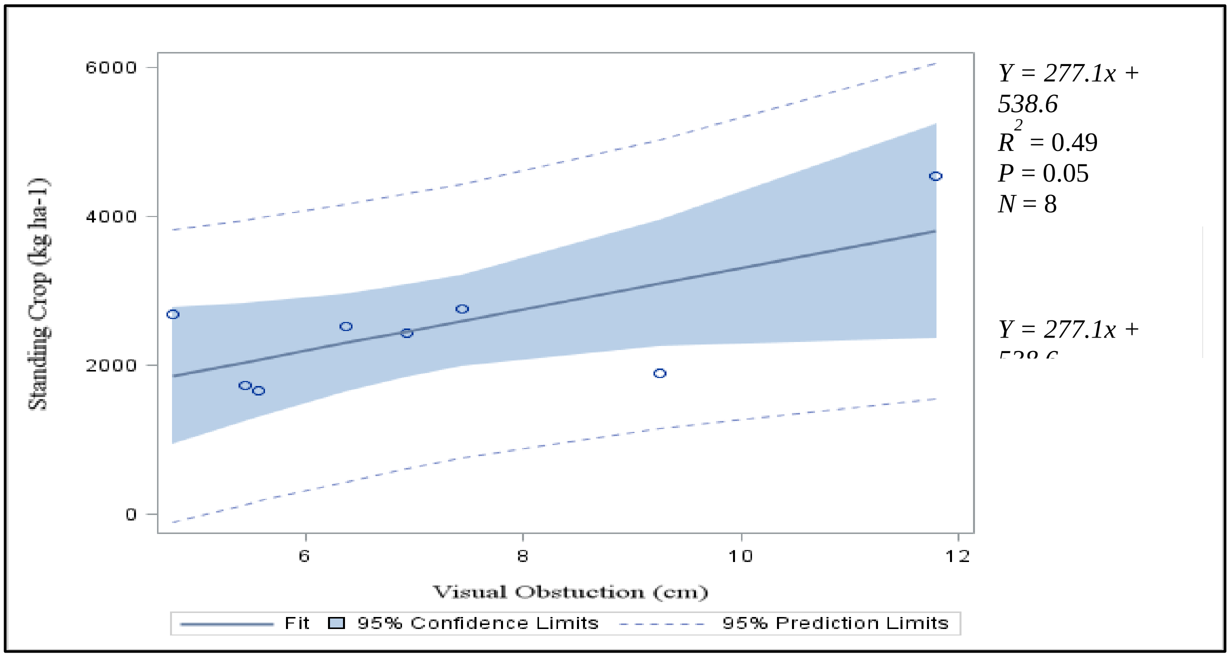


Figure A 20. Linear regression model for thin loamy ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2013.

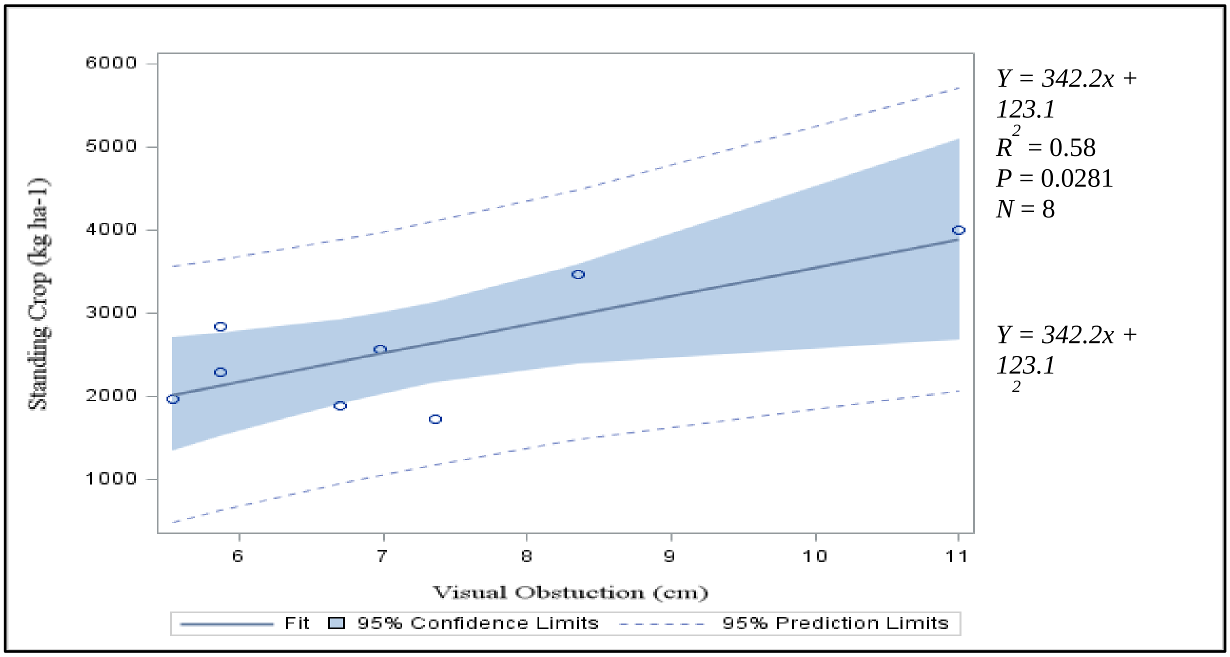


Figure A 21. Linear regression model for claypan ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2013.

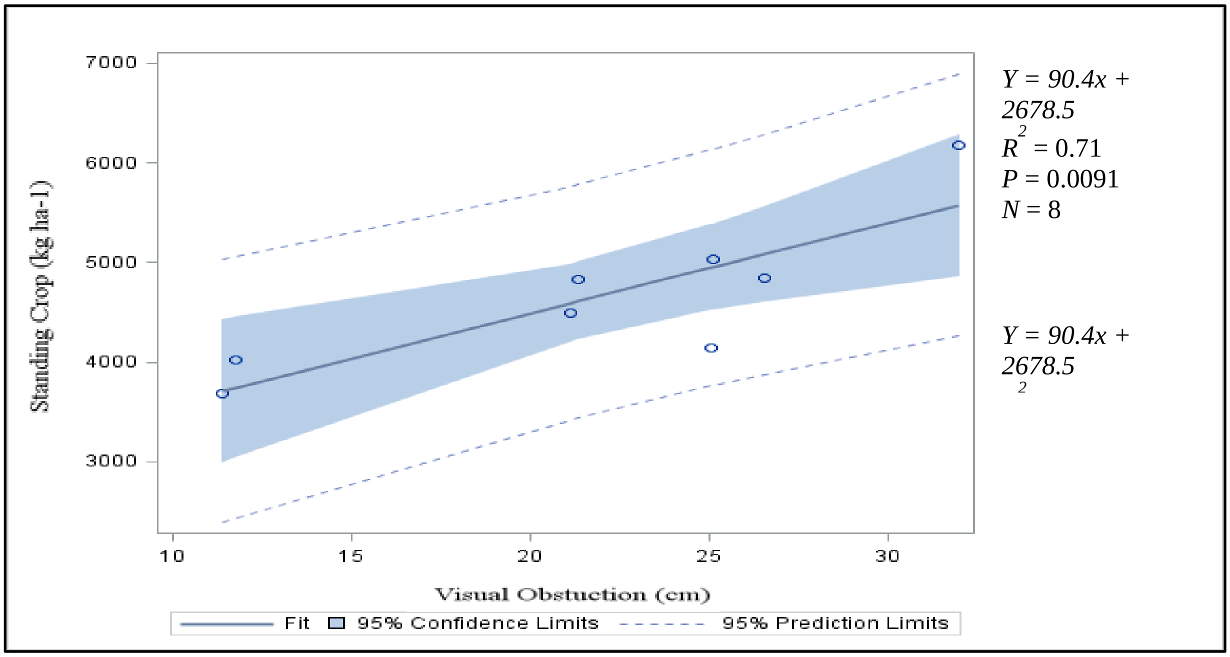


Figure A 22. Linear regression model for loamy ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2012.

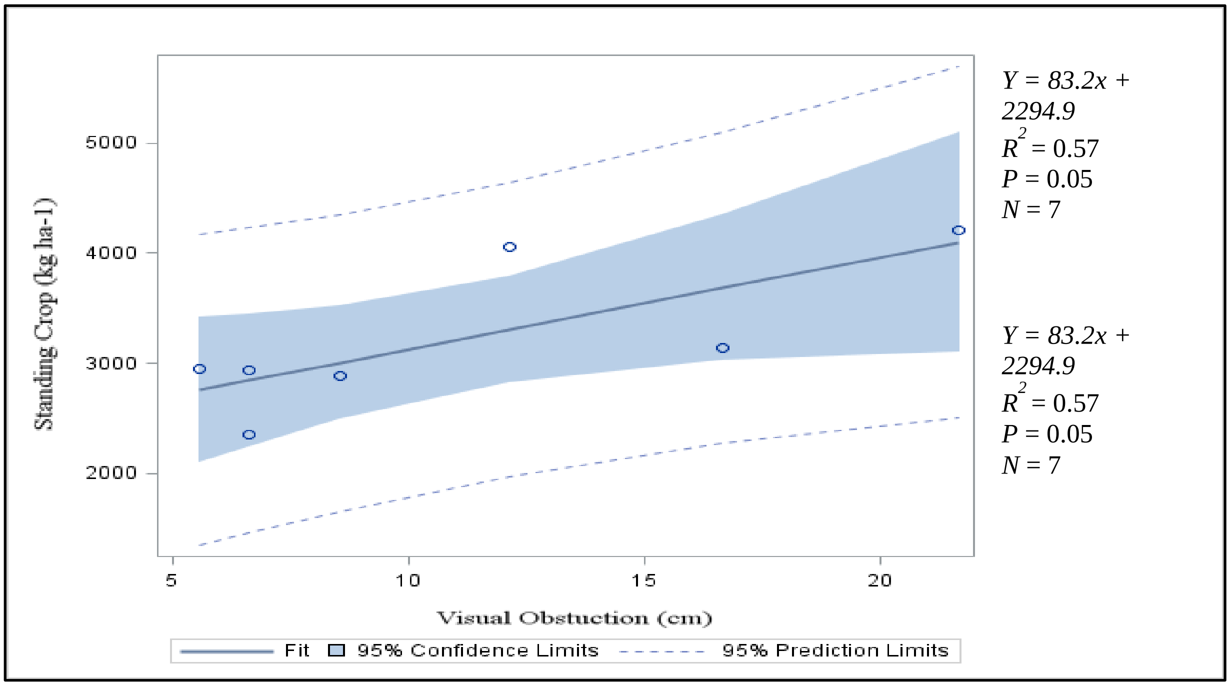


Figure A 23. Linear regression model for thin loamy ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2014.

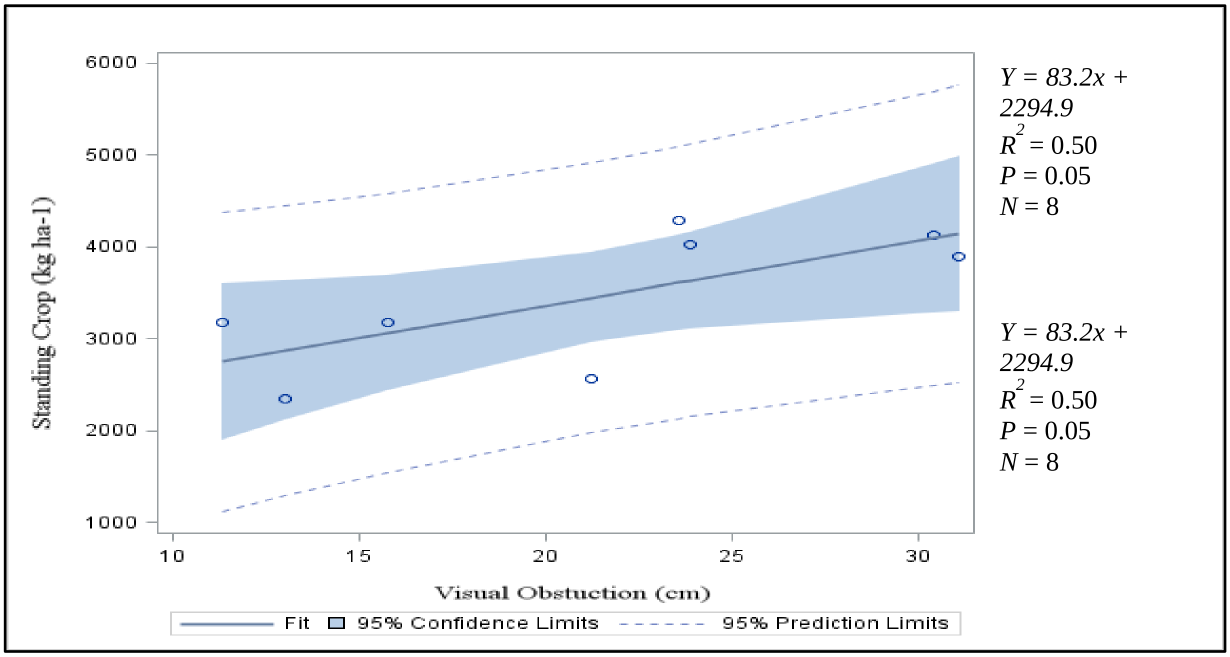


Figure A 24. Linear regression model for claypan ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2014.

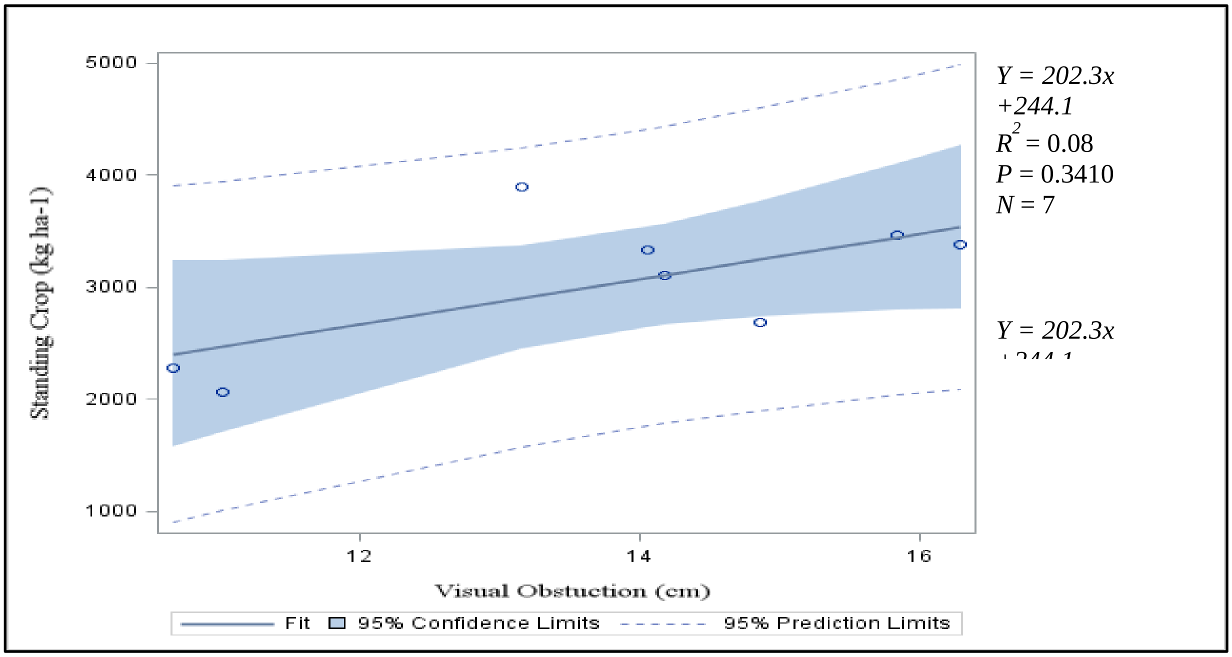


Figure A 25. Linear regression model for loamy ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2014.

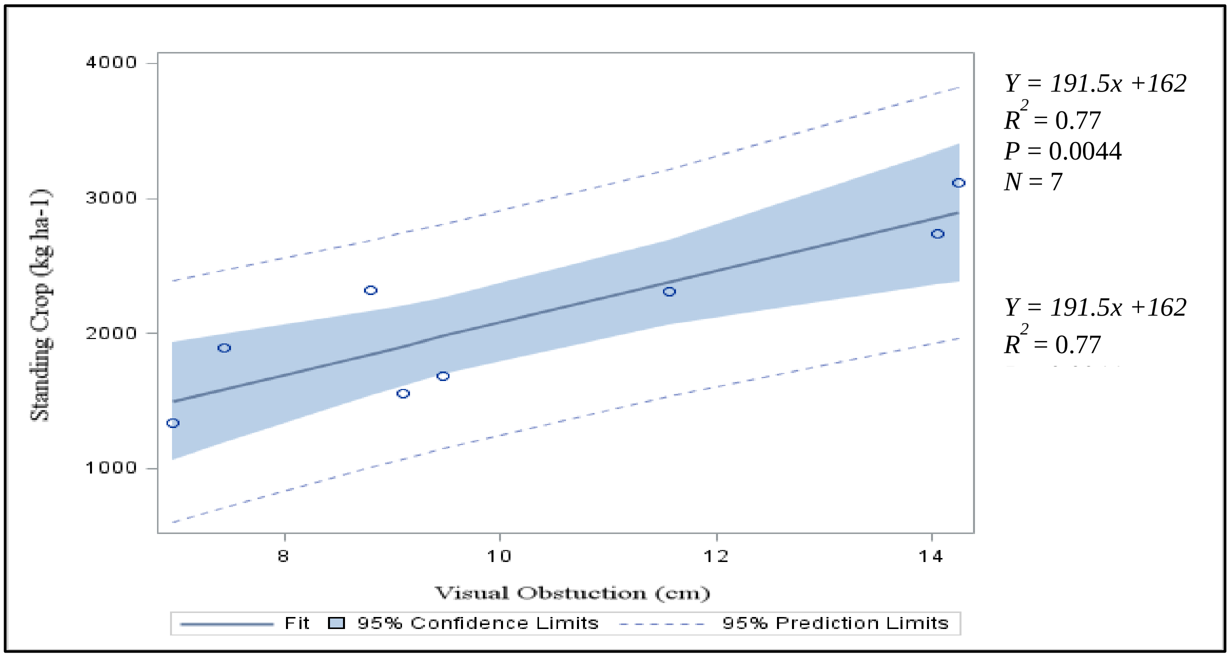


Figure A 26. Linear regression model for thin loamy ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2014.

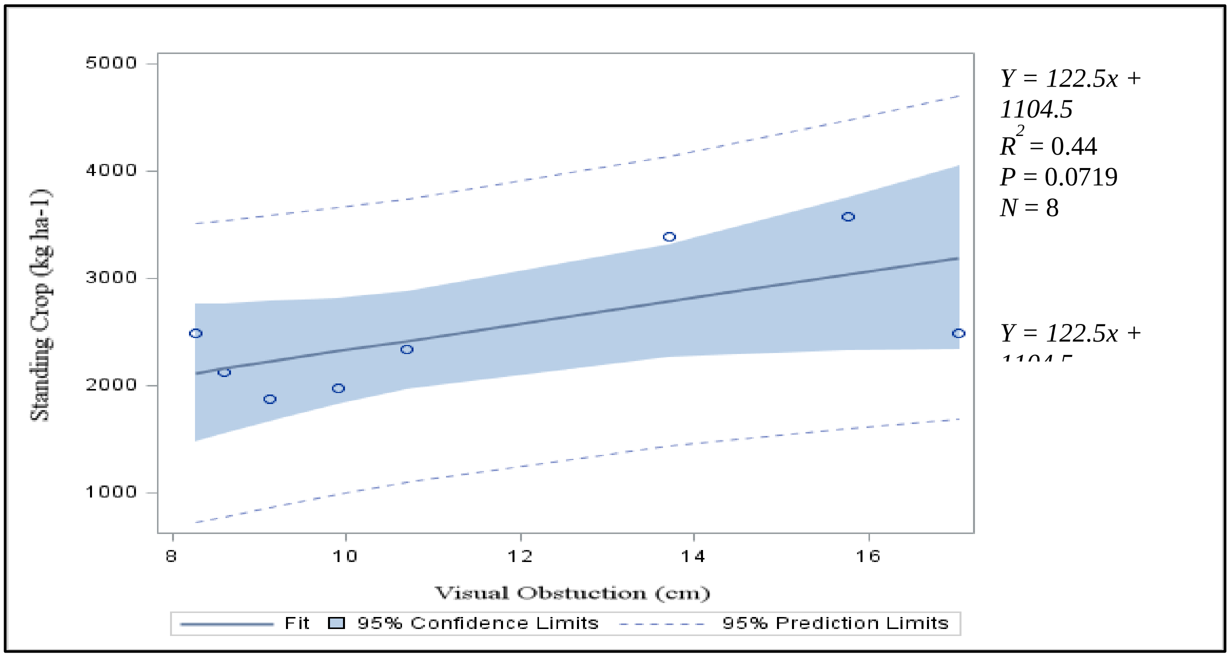


Figure A 27. Linear regression model for claypan ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for July, 2014.

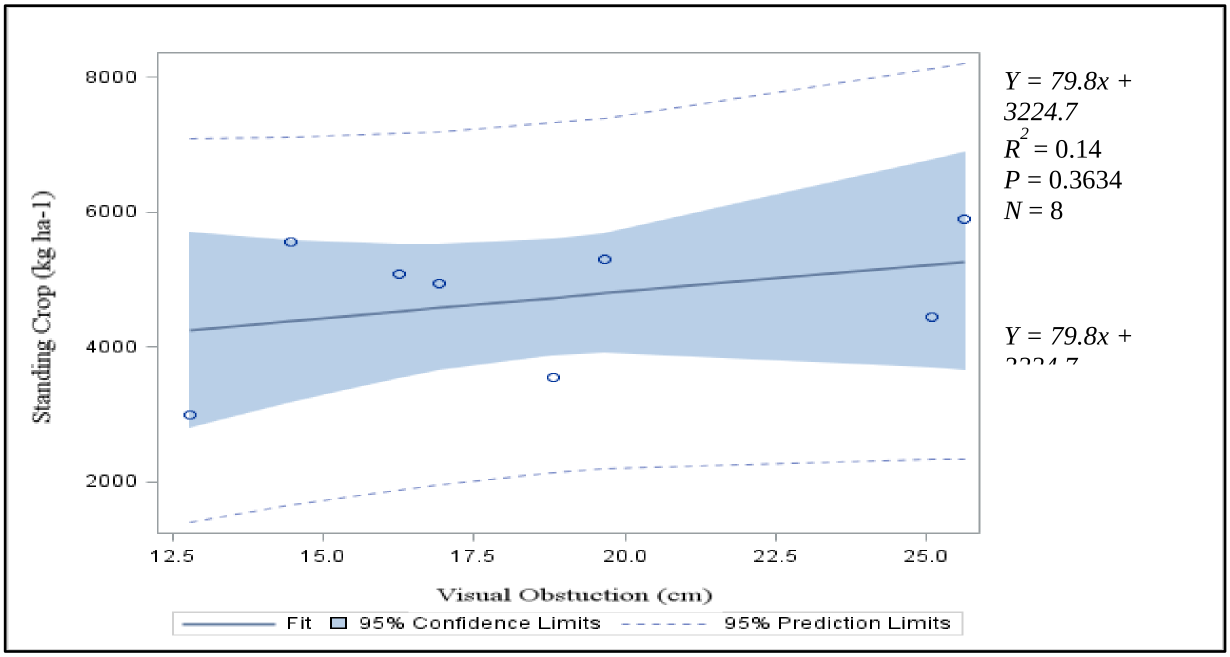


Figure A 28. Linear regression model for loamy ecological sits at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2014.

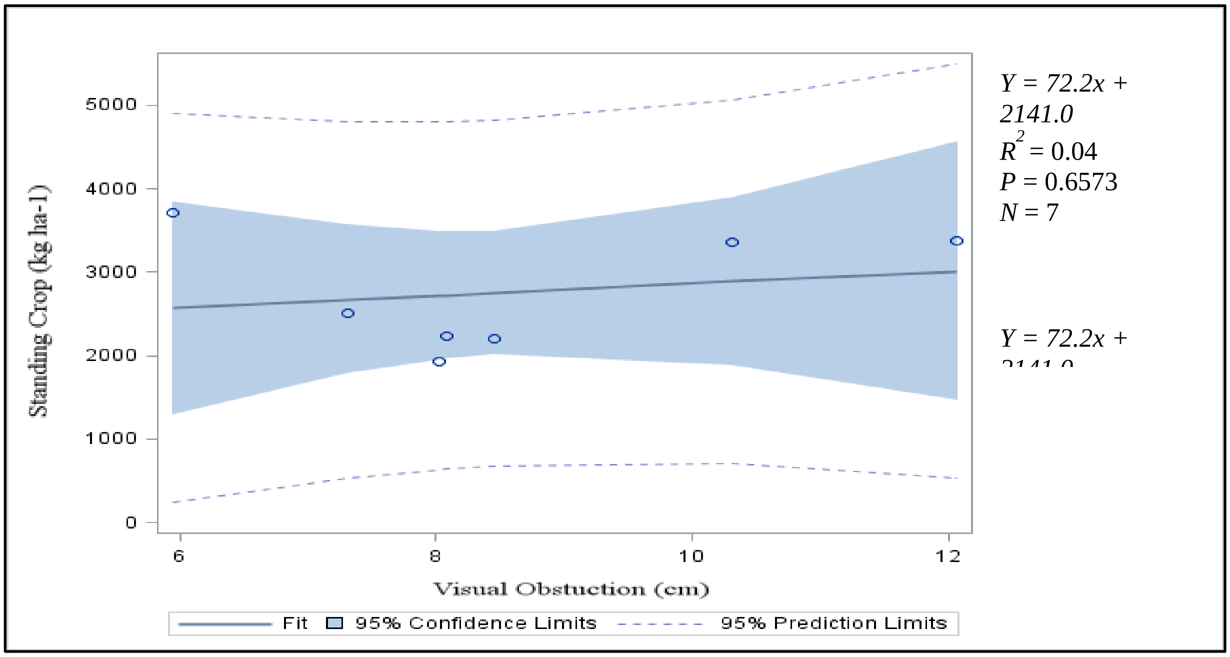


Figure A 29. Linear regression model for thin loamy ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2014.

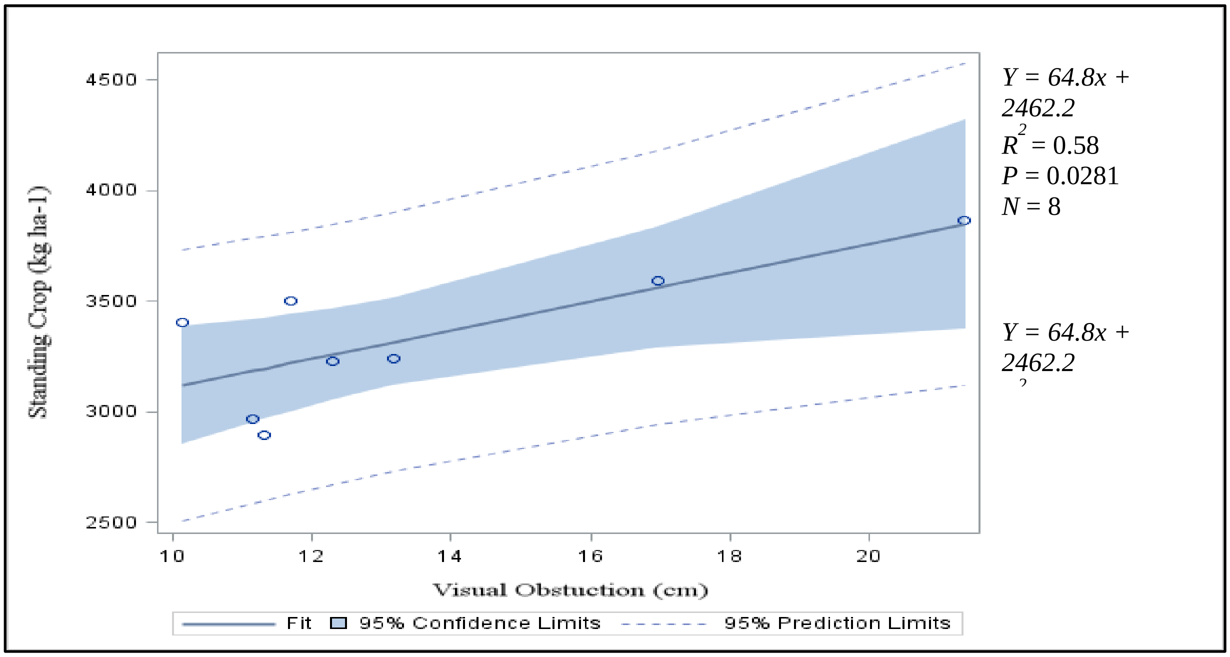


Figure A 30. Linear regression model for claypan ecological sites at the Grand River National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2014.

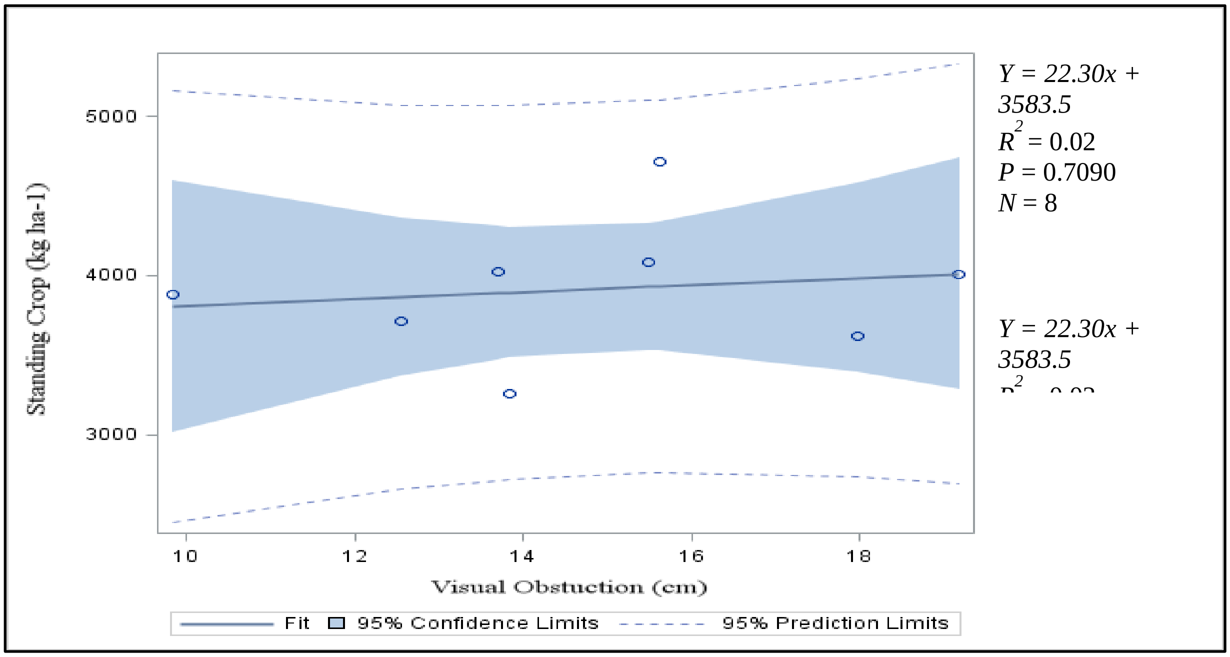


Figure A 31. Linear regression model for loamy ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2014.

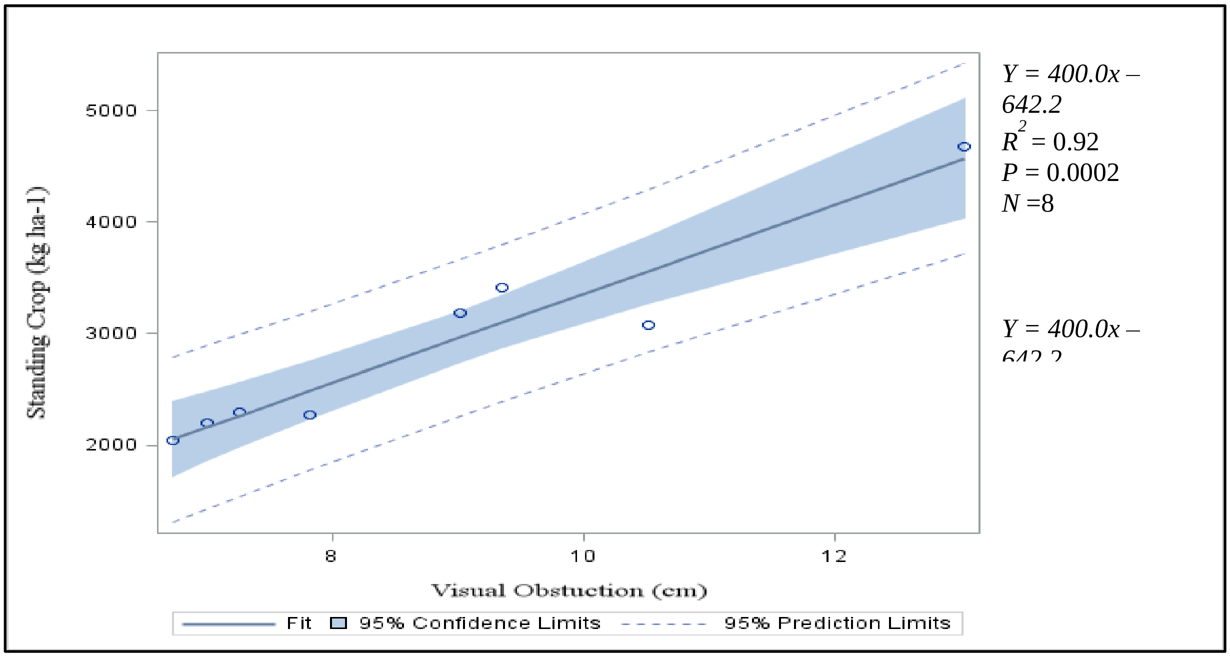


Figure A 32. Linear regression model for thin loamy ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2014.

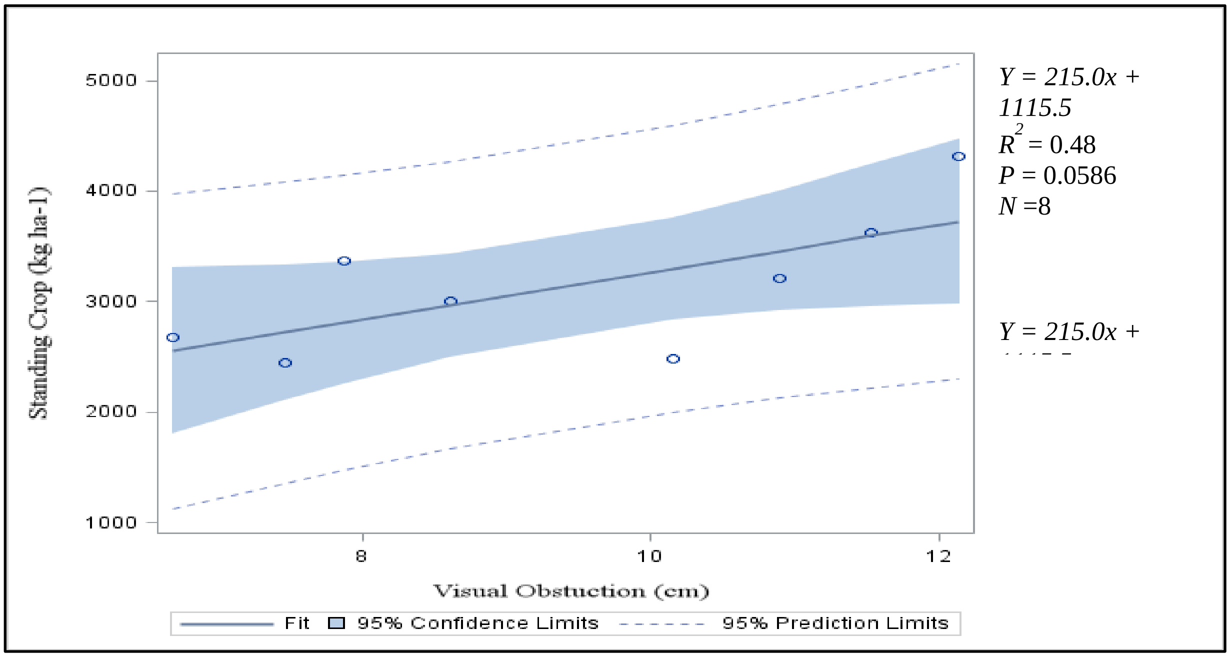


Figure A 33. Linear regression model for claypan ecological sites at the Little Missouri National Grasslands with associated regression model, 95% confidence, and prediction limits for October, 2014.

APPENDIX B. VISUAL OBSTRUCTION READING FOR EACH ECOLOGICAL SITE ON THE GRAND RIVER NATIONAL GRASSLANDS AND LITTLE MISSOURI NATIONAL GRASSLANDS IN OCTOBER 2011

Table B 1. Mean visual obstruction reading (VOR) and standard error (SE) in cm for all ecological sites on the Grand River National Grasslands (GRNG) and Little Missouri National Grasslands (LMNG) in October 2011.

	GRNG			**LMNG**		
	Loamy	**Thin Loamy**	**Claypan**	**Loamy**	**Thin Loamy**	**Claypan**
Mean VOR	8.2	6.6	10.0	14.2	11.2	11.7
SE	± 0.30 (7.90-8.50)	± 0.37 (6.23-6.97)	± 0.37 (9.63-10.37)	± 1.71 (12.49-15.91)	± 0.44 (10.76-11.64)	± 0.56 (11.14-12.26)

APPENDIX C. SIMILARITY INDICES AND PLANT COMMUNITY PHASES FOR ALL ECOLOGICAL SITES IN 2012 AND 2014

Table C 1. Similarity indices and plant community phases for loamy ecological sites at the Grand River National Grasslands in 2012 and 2014.

	2012		2014	
Plot ID	Similarity Index	Plant Community Phase	Similarity Index	Plant Community Phase
LM2CH6-2	59	2.3	68	2.3
LM2CH9-9	70	2.1	71	2.3
LM3B3-3F	61	1.1	52	1.1
LM4AN3-3	52	2.3	45	3.1
LM4AS2-3	64	2.3	21	3.1
LM4AS2-3B	42	3.1	50	2.3
LM4AS3-3	61	2.3	33	2.3
LM4NW2-2	47	2.1	29	3.1

Table C 2. Similarity indices and plant community phases for thin loamy ecological sites at the Grand River National Grasslands in 2012 and 2014.

	2012		2014	
Plot ID	Similarity Index	Plant Community Phase	Similarity Index	Plant Community Phase
LB3-1	33	3.3	29	3.3
LB3B-1	40	2.2	50	1.1
LB3B9-9	38	3.3	N/A[1]	N/A[1]
LB4BN3-1	42	3.3	59	3.3
LB8-1	33	3.3	51	3.3
LB8-2	47	2.2	43	2.2
LB8-4	47	1.1	40	3.3
TL8-3	48	3.3	51	1.1

[1] N/A indicated not available

Table C 3. Similarity indices and plant community phases for claypan ecological sites at the Grand River National Grasslands in 2012 and 2014.

	2012		2014	
Plot ID	Similarity Index	Plant Community Phase	Similarity Index	Plant Community Phase
CP2CD-1	52	2.1	44	3.1
CP8-1	40	2.3	47	2.3
CP9-1	23	3.1	64	2.3
CP9-2	46	3.1	31	3.1
CP9-3	49	2.3	52	2.3
CP9-4	50	2.3	48	2.3
CP9-5	51	2.3	48	2.1
CP9-6	46	3.1	49	2.3

Table C 4. Similarity indices and plant community phases for loamy ecological sites at the Little Missouri National Grasslands in 2012 and 2014.

	2012		2014	
Plot ID	Similarity Index	Plant Community Phase	Similarity Index	Plant Community Phase
LM-1	56	2.1	68	1.1
LM-2	54	2.3	49	3.1
LM-3	56	2.3	42	2.3
LM-4	69	2.1	51	2.1
LM-5	66	1.1	59	1.1
LM-6	56	1.1	60	2.1
LM-7	60	1.1	59	1.2
LM-8	53	2.1	61	2.1

Table C 5. Similarity indices and plant community phases for loamy ecological sites at the Little Missouri National Grasslands in 2012 and 2014.

	2012		2014	
Plot ID	Similarity Index	Plant Community Phase	Similarity Index	Plant Community Phase
TL-1	59	1.1	48	1.1
TL-2	64	1.1	73	2.2
TL-3	47	3.3	49	2.2
TL-4	48	2.2	54	1.1
TL-5	56	2.2	49	1.1
TL-6	56	1.1	61	3.3
TL-7	58	2.1	48	1.1
TL-8	57	1.1	34	5.5

Table C 6. Similarity indices and plant community phases for claypan ecological sites at the Little Missouri National Grasslands in 2012 and 2014.

	2012		2014	
Plot ID	Similarity Index	Plant Community Phase	Similarity Index	Plant Community Phase
CP-1	67	1.1	48	2.1
CP-2	54	1.3	47	2.1
CP-3	41	1.1	57	1.1
CP-4	40	2.2	62	2.1
CP-5	40	1.1	53	2.1
CP-6	63	2.3	51	2.1
CP-7	57	2.1	52	1.1
CP-8	45	1.1	43	1.1