A COMPARISON OF RANGELAND MONITORING TECHNIQUES FOR RELATIVE SPECIES ABUNDANCE IN NORTHERN MIXED GRASS PRAIRIE

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Aaron Field

In Partial Fulfillment
of the Degree of
MASTER OF SCIENCE

Major Program:
Natural Resources Management

February 2014

Fargo, North Dakota

North Dakota State University
Graduate School

Title

A Comparison of Rangeland Monitoring Techniques for Relative Species Abundance in Northern Mixed Grass Prairie

By

Aaron L. Field

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

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Kevin Sedivec
Chair

Jack Norland

Edward DeKeyser

Gary Clambey

Approved:

3/11/14
Date

Kevin Sedivec
Department Chair

ABSTRACT

Clipping by species is one of the most accurate methods available for determining species composition. However, cost and time constraints often make clipping by species impractical on any large scale. Our objective was to determine whether either of two less labor intensive methods (line point intercept, quadrat frequency frame) could provide suitable alternatives to clipping. Data was collected as part of a rangeland monitoring project on the Dakota Prairie Grasslands. Each method was used to inventory grassland plant species within the same plots, which allowed us to analyze the results for each method side by side. Our findings indicate that for relative rankings of species abundance, both line point intercept and quadrat frequency frames produce a similar result as clipping and could be used interchangeably. We suggest using either line point intercept or quadrat frequency frames to produce such a list because of the reduced time inputs involved.

ACKNOWLEDGEMENTS

I have many people to thank for getting me to this point in my education. First, I would like to thank the McKenzie County Grazing Association and United States Forest Service for providing the necessary funding to make this study possible. Also my wife Jenny for supporting me these past few years. Few people would be able to accept that sitting in a chair staring at a computer screen was productive work, but she has always understood. Whenever I nearly snapped from statistics and repeating data entries she helped me keep my sanity. Next, my coworkers. It is amazingly encouraging to have people who understand your frustration and excitement over plant community data and significant p values. Next, I have been lucky enough to have excellent field crews over the years. Clipping, quadrats, line point, and ten pin for ten to twelve hours in 95 degree heat would have been unbearable without hardworking, pleasant help. Without Dennis and Gary especially, I would have been completely lost. Continuing, my professors and committee members, Jack Norland, Shawn DeKeyser, and Gary Clambey, who have always been as willing to help as if I was their own advisee. Finally, my advisor. Kevin always seems able to do as much in ten minutes as most people could in an hour, which is good because he rarely has an hour to spare. Beyond that he has always allowed me the freedom to work in my own manner as long as my work is completed on time and at a high standard. I feel that this leadership style will help me greatly as I continue my career and I hope to learn more in the future. To all that I have mentioned, and many more who I haven't, thank you very much.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

LIST OF ABBREVIATIONS

AVHRR……………………………………………Advanced Very High Resolution Radiometer
BLM…………………………………………………………..Bureau of Land Management
DPG…………………………………………………………...Dakota Prairie Grasslands
LCTA…………………………………………………………Land Condition-Trend Analysis
MLRA………………………………………………………...Major Land Resource Area
NDVI…………………………………………………Normalized Difference Vegetation Index
NMS…………………………………………………..Nonmetric Multidimensional Scaling
NRCS……………………………………………………Natural Resource Conservation Service
NRI…………………………………………………………..Natural Resource Inventory
USFS………………………………………………………...United States Forest Service
VOR………………………………………………………...Visual Obstruction Readings

INTRODUCTION

Rangelands and grasslands cover approximately 50% of the earth's terrestrial surface (Williams et al. 1968). These areas provide vital forage for livestock as well as crucial wildlife habitat. Less obvious but equally important functions of rangeland include carbon sequestration, water cycling, and erosion control (Havstad et al. 2007). Land managers must monitor rangeland vegetation to determine whether their management decisions are producing desired results; however, detailed monitoring of these huge tracts of land is both expensive and time consuming.

Some methods, such as photo-points or visual cover estimation, take little time or expertise to perform, but give only very basic information. Other methods, like above-ground biomass clipping, can give very detailed and accurate information about a rangeland plant community, but are time consuming and therefore expensive (Bonham 1989). In some cases, detailed information may be necessary. In many other situations a relative species abundance ranking will be adequate. This ranking can give managers a fairly comprehensive species list, identify dominant species, and recognize invasive species. They can also be produced with less time consuming methods than clipping. Our objective for this study was to determine whether these less time consuming methods could provide a suitable alternative to clipping in large scale monitoring projects. If this proves true, land managers, land owners, and researchers would have the option of increasing frequency of monitoring (versus clipping), increasing amount of land monitored, or simply reducing the time and monetary input required for monitoring.

We propose that techniques requiring a moderate time input, such as quadrat frequency frames and line point intercept methods, provide the best balance between detailed information and time input when monitoring large areas. To test this hypothesis we compared the relative plant community composition hierarchies produced by two moderate input methods (line point intercept and quadrat frequency) to those produced by clipping by species in two common ecological sites in western North Dakota.

LITERATURE REVIEW

Quadrat Frames

Quadrat frames are a commonly used tool in modern plant community composition studies. They are used in many ecosystems including wetlands (e.g., Lopez and Fennessy 2002), forests (e.g., Archaux et al. 2007), and rangelands (e.g., Mosley et al. 1989). Quadrat frames have been used since at least 1912 (Priestly 1913), with further use in rangelands as early as 1914 (Ramsey 1916).

The quadrat frame has been used in many different ways. Sampson (1917) listed three ways to use the quadrat: mapping the size and location of each plant within the frame, listing each species within the frame, or removing all plants from the frame and recording the repopulation. Weaver and Clements (1929) described use of quadrats as grids and also as a random sample. They also discussed varying the size and number of quadrats based on type of vegetation studied. For example, larger quadrats would be used in a sagebrush community than in a mixed-grass prairie. Also, more samples should be taken in a diverse, variable community than are necessary in a relatively homogeneous community.

Wiegert (1962) discussed the harmful edge effects seen when using a quadrat that is too small. He also created a method for determining the optimum quadrat size and shape using calculated variance at different quadrat sizes. Despain et al. (1991) recommended using a square quadrat of 40-50 cm per size in most locations. They also advocated use of nested quadrats of varying size to monitor species of varying sizes and frequencies. These researchers also stated that "the best sampling precision is reached for a particular species when it is present in 40% to 60% of the quadrats sampled. This will provide the most sensitivity to changes in frequency." West (1985) warned that managers should not attempt to calculate percent composition from frequency data, and Hironaka (1985) stated that other methods should be used in conjunction with quadrat frequency if time and money are available.

Daubenmire (1959) described a quadrat method for determining canopy cover. He used 6 canopy cover classes to quantify plant communities. However, Floyd and Anderson (1987) and Kennedy and Addison (1987) recommended that quadrats not be used for cover estimation. Cain (1943) used the quadrat frame as a method for determining plant communities based on frequency, and Curtis and McIntosh (1950) described various methods for analyzing quadrat data, including frequency, density, abundance, constancy, and presence. Quadrat frames are useful in recording rare species, as the area covered by the method is quite large. Time inputs vary based on use, with canopy cover mapping being quite time consuming while frequency determination requires less time. Frequency monitoring does have the problem of weighting a single species within the quadrat the same as a species that appears several times. Greig-Smith (1983) determined that the relationship from frequency to density is only consistent when plants are evenly distributed. Hironaka (1985) found that plant frequency monitoring was faster and cheaper than any other method if your goal is detecting changes in community composition. Recently, researchers have continued to use the quadrat frame for vegetation monitoring and are also working to compensate for sampling bias in the method (Clarke et al. 2011). Heywood and DeBacker (2007) found that a plot size producing an average of about 50% frequency yields nearly maximum statistical power, and that revisiting the same sites over time increased statistical power, which agrees with the findings of Despain et al. (1991). DeBacker et al. (2011) used differential plot sizes ranging from 0.01 m^2 to 10 m^2 to reach an optimal plot size for species growing in a tallgrass prairie system. They found that in order to reach an optimum frequency for detecting changes, plot sizes needed to vary between common and less common species of concern. They recommend determining the optimal plot size for each species of concern and using plots of that size to monitor changes over time.

Harvest Method: (Clipping Above-ground Biomass)

Clipping has been used as a monitoring technique since at least the late 1800's. Fream (1888, 1890) removed turf and soil samples from the field and grew them in a laboratory to maximum production, before clipping the above ground mass and weighing it without drying. Stapleton (1913) used a clipping technique to measure production, also weighing green vegetation. Roberts (1933) dried the green biomass before weighing in order to obtain a more accurate production value. Clipping, particularly by separating each species in the sample, has several advantages. It is very accurate and removes much of the observer bias that is seen in other techniques. The method also gives an accurate portrayal of the biomass production of the area, which is especially useful in setting stocking rates for grazing animals. In recent years, clipping by species has been used in rangeland management for similarity indices. These indices compare the production of each species at a given site with the probable historical production of native species.

An issue with clipping by species is the amount of time required to sort through all of the plant species in a given clipping. Bonham (1989) noted that biomass estimation by harvesting is "time consuming and expensive." This is especially true when working in a diverse plant community. Because of this problem, several researchers have tried to correlate clipping data with less time consuming methods, especially visual obstruction readings (VOR). Benkobi et al. (2000) and Uresk and Mergen (2012) both found correlations between above ground production and VOR, but their correlation coefficients varied by ecosystem. Ahmed et al. (1983) and Brummer et al. (1994) tested the efficacy of different quadrat shapes, but no shape was found to be superior in accuracy. Clark et al. (2008) compared the point intercept method with clipping in sagebrush steppe ecosystems and found point intercept as accurate as clipping but less time consuming. Thoma et al. (2002) used Advanced Very High Resolution Radiometer (AVHRR) Imagery to produce a Normalized Difference Vegetation Index (NDVI), which they then compared to clipping data, again in an attempt to reduce the time and energy expended in monitoring. They found that AVHRR had the potential to predict forage values at a regional level, but had no ability to determine species composition. Epstein et al. (2012) compared clipping data to satellite derived Normalized Difference Vegetation Indices (NDVF) to attempt to improve the NDVI system in tundra ecosystems. They found that they needed extensive ground level harvesting to strengthen the model.

Another issue with biomass clipping is the time required to transport samples to the laboratory for drying and the time spent drying. This transportation and weighing process creates more chances for data to be mislabeled or misplaced. The equipment needed (e.g., clipping hoops or frames, clippers, bags, labels) also adds significant weight to the researcher's pack when working in remote locations.

Point Intercept (Multi and Single Point Methods)

Everson and Clarke (1987) stated that "when a sampling quadrat is reduced to a dimensionless point, frequency becomes an absolute measure of cover." The point method of vegetation monitoring was developed in New Zealand by Levy and Madden (1933). The first frame consisted of a wooden horizontal bar supported by strips of steel. Ten steel needles were inserted through the wooden bar at two inch intervals. Any plant contacted by a pin at any height was recorded. Often, the height at which the contact was made was recorded. Modifications to the frame to add a brake system (Heady and Rader 1958) and a hinged leg for easier storage and angled reading (Smith 1959) helped make the point frame easier to use. Wilson (1960) found that angling points at 32.5 degrees produced the least variation from foliage angle. Nerney (1960) added a bicycle tire to the frame, but that improvement has not been as popular. To measure both canopy and basal cover, a single pin is often substituted for the pin frame. In this variation of the method, all plant species that contact the pin are recorded, as well as the ground cover that the tip of the pin touches.

Early verification of the point intercept method's validity was done by Goodall (1952), Whitman and Siggeirson (1954), and Heady (1957). Since then the single point intercept method has been used extensively in the Natural Resource Inventory (NRI) performed by the Natural Resource Conservation Service (NRCS) to measure both canopy and basal cover. Several other federal agencies use the method including the Bureau of Land Management (BLM) and the United States Forest Service (USFS). The ten point intercept method has become one of the most common methods for determining ground cover.

Ecological Sites

An ecological site is defined as "a distinctive kind of land with specific physical characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation" (Sedivec and Printz 2012, USDA-NRCS 2006). Our study area comprised many different ecological sites, but the two most common ecological sites were the loamy and the thin loamy ecological sites. Therefore, we chose to focus on these sites in our analysis.

The loamy ecological site is the most common ecological site in North Dakota. These sites are on uplands with a surface soil layer that forms less than a 2-inch ribbon of silt loam or loam. Subsoil layers form a less than 2-inch ribbon of silt loam to clay loam. The upper part of the subsoil is none to slightly effervescent (Sedivec and Printz 2012). The plant community is comprised of about 85% grasses and grass-like plants, 10% forbs, and 5% shrubs. The plant community is dominated by western wheatgrass (*Pascopyrum smithii*) and green needlegrass (*Nassella viridula*), with needle-and-thread (*Hesperostipa comate*), blue grama (*Bouteloua gracilis*), porcupine grass (*Hesperostipa spartina*), and sedges (*Carex spp.*) common as well. Common forbs include American vetch (*Vicia americana*), green sagewort (*Artemesia dracunculoides*), silverleaf scurfpea (*Pediomelum argophyllum*) and Missouri goldenrod (*Solidago missouriensis*). Western snowberry (*Symphoricarpos occidentalis*) is the principal shrub and occurs in patchy mosaic. In other areas, silver sagebrush is the dominant shrub and occurs more evenly dispersed across the site (USDA-NRCS 2003). The combination of gentle slopes and optimal available water content make these sites one of the most productive ecological sites in MLRA (Major Land Resource Area) 54 and 58C, with annual production averaging about 2400 kg/ha.

The thin loamy ecological site was the second most common site in our study area. In a thin loamy ecological site the surface layer forms a less than 2-inch ribbon of silt loam or loam. The subsoil layer forms a ribbon of silt loam to clay loam less than 2-inch in length. These soils have none to strong effervescence in the surface layer and strong to violent effervescence in the subsoil. These sites occur on ridges and knolls (Sedivec and Printz 2012).

The plant community is comprised of about 85% grasses or grass-like plants, 10% forbs, and 5% shrubs. The major grasses include the needle-and-thread, green needlegrass, western wheatgrass, little bluestem (*Schizachyrium scoparium*), and sideoats grama (*Bouteloua curtipendula*). Other grasses occurring on the site include blue grama, plains muhly (*Muhlenbergia cuspidata*), and red threeawn (*Aristida purpurea*). The increased slope, and consequently increased runoff, of the thin loamy site leads to less production, averaging about 1500 kg/ha in MLRA 54 and 58C.

STUDY AREA

Our study took place on the Dakota Prairie National Grasslands of western North Dakota, which are managed by the United States Department of Agriculture - United States Forest Service (USFS). These National Grasslands cover over 500,000 hectares and are split into four ranger districts: Medora Ranger District, McKenzie Ranger District, Sheyenne Ranger District, and Grand River Ranger District. Our data were collected in the McKenzie and Medora districts by researchers based in three research regions: McKenzie County, Billings County, and Slope County.

Historically, the grasslands of this region were grazed by bison, elk, and other native herbivores (Hanson 1984). They were also subjected to disturbance from fire (Wells 1970). In the past 150 years, cattle have been the dominant large herbivore on these grasslands. Cattle grazing has been a major component of the USFS multiple-use strategy since the agency was formed in 1891. Fire has also been used but is not as common and often met with resistance. In our study area, and many other National Grasslands, grazing has been managed cooperatively by the USFS and local grazing associations. These associations are made up of landowners and lessees (permittees) who graze federal lands, and were created to prevent smaller ranchers from being pressured to sell by large corporations or the federal government. This relationship has not been without conflict, but research-based, cooperative decisions can help reduce controversy, especially when stocking rates are involved. The grazing associations within our study area included the Little Missouri, McKenzie, Medora, and Grand River Grazing Associations.

Our study locations were located within MLRAs 54 and 58C. MLRA 54 is described as rolling soft shale plain (USDA-NRCS 2006). The soil parent material of the region is soft, calcareous shales, siltstones, and sandstones. The dominant soil orders of this MLRA are Mollisols and Entisols, and the northern and eastern parts of the area have been modified by glaciation. The average annual precipitation of MLRA 54 is 355-455 mm and average annual temperature 3-8 degrees C. Nearly all of this MLRA is farmed or ranched, and about half of the area supports native grasses and shrubs that are grazed. The natural prairie vegetation expected would be northern mixed-grass prairie, with green ash (*Fraxinus pennsylvanica*), chokecherry (*Prunus virginiana*), and buffaloberry (*Shepherdia argentea*) occurring in draws and ravines. The vegetation of this region supports many wildlife species including whitetail deer, mule deer, pronghorn antelope, prairie dogs, and many bird species.

MLRA 58C is described as the northeastern part of the northern rolling high plains. This area consists of rolling hills and badlands. The soil parent material includes marine sediments, shale, siltstone, and sandstone. Mollisols are present, but Entisols and Inceptisols are common due to a widespread occurrence of steep slopes and erosion caused by these slopes. The average annual precipitation of this area is 355-430 mm and average annual temperature 5-7 degrees C. MLRA 58C land use is dominated by ranching and recreation. Only 5% of the MLRA is cropland (USDA-NRCS 2006). Northern mixed-grass prairie occurs in most of the area, with barren badland outcrops being fairly common. This MLRA also supports many species of wildlife.

Ecological Sites

We limited our analysis to the two most common ecological sites to ensure an adequate sample size in each. Our monitoring plots were selected to assess the status of the two most common ecological sites in each allotment, which provided the most data on loamy and thin loamy ecological sites.

The loamy ecological site is the most common ecological site in North Dakota. These sites are on uplands with silt loam to clay loam textured soils. These are typically well developed soils with few remaining carbonates at the surface (Sedivec and Printz 2012). The historic climax plant community of this ecological site includes green needlegrass, western wheatgrass, blue grama, and several native forb species. The combination of gentle slopes and optimal available water content make these sites one of the most productive ecological site in MLRA 54 and 58C, with annual production averaging about 2400 kg/ha.

The thin loamy ecological site was the second most common site in our study area. Thin loamy ecological sites display loam to clay loam soils that are less well developed than those found on loamy sites. These soils often contain significant amounts of carbonates and occur on ridges and knolls (Sedivec and Printz 2012). The historic climax plant community of thin loamy sites includes little bluestem, western wheatgrass, sideoats grama, sedges, and several species of more drought tolerant forbs and shrubs. The increased slope, and consequently increased runoff, of the thin loamy site leads to less production, averaging about 1500 kg/ha in these MLRAs.

Precipitation

Growing season precipitation in the southern portion of our study area (Figure 1) was slightly above average. In the northern portion (Figure 2) growing season precipitation was somewhat below average. We feel that this amount of variation from the mean is normal and has had no effect on our comparison of methods.

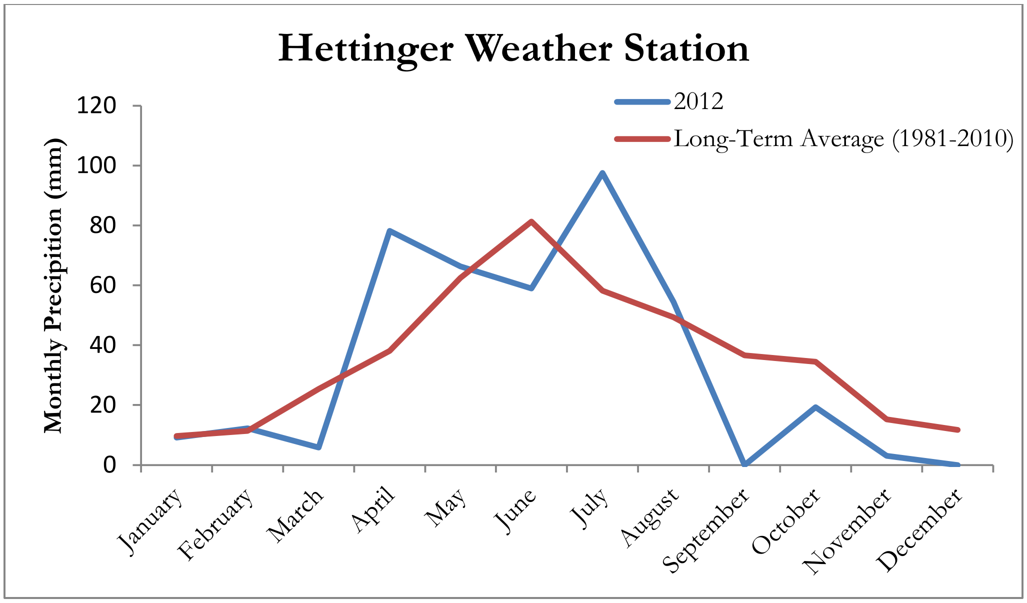

Figure 1. Monthly precipitation (mm) at Sidney, MT weather station for 2012 and long-term average (USDC Commerce 2012a).

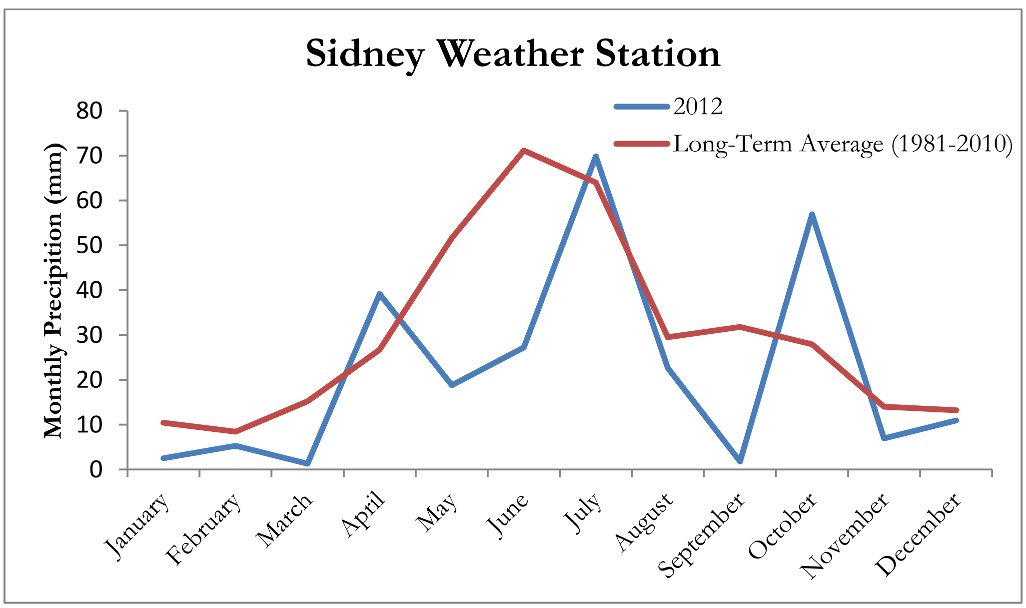

Figure 2. Monthly precipitation (mm) at Hettinger, ND weather station for 2012 and long-term average (USDC Commerce 2012b).

METHODS

Plot Location

Monitoring plots for a large scale study on the Dakota Prairie Grasslands (DPG) were located using a systematic approach followed by random selection. Each allotment or grazing unit was stratified by ecological site using the USDA-NRCS soil layers for McKenzie, Billings and Slope counties in North Dakota, and Perkins county South Dakota. Once the ecological site layer was created, the two dominate ecological sites, in terms of acres, were selected for data collection. Three or more plots were selected randomly for each ecological site within each grazing allotment. Two hundred meter buffer exclusion was created from the roads, and 100 m buffer exclusion from the water tanks, fences, and pipelines.

From these plots listed in the previous paragraph, the loamy and thin loamy ecological sites were chosen for this study. The loamy and thin loamy ecological sites were two of the most common ecological sites found on the DPG. In all, 61 randomly selected loamy ecological site plots and 39 randomly selected thin loamy ecological site plots monitored in 2012 were used for comparing selected monitoring practices.

Ecological Site Determination

Two 75m transects were laid out perpendicular to each other facing each cardinal direction at each plot location. A soil pit was dug near the center point at a location that best fitted the majority of the plot. Soil and landscape position information was used to determine the major ecological site of the plot. Plots, classified as loamy and thin loamy, were used for our analysis.

Method: Clipping by Species

A 0.178 m^2 hoop was placed at 20m intervals along each transect (totaling six hoops per plot). All live plant species rooted within the hoop were clipped to ground level and placed in individual bags. Previous year's growth and litter were also collected and placed in separate bags. These bags were then oven dried at 105ºC for 72 hours and weighed to the nearest 0.1 g. The average weight of each species was then determined by dividing the total weight of each species on a plot by the six clippings. This average weight was used to create a species ranking for each plot.

Method: Quadrat Frequency Frame

A 0.25 m^2 steel frame was placed at 10m intervals along each transect (totaling 14 frames per plot). All forb or shrub species rooted were counted within the frame at each point to determine density. A 0.1 m^2 frame nested within the 0.25 m^2 frame was used to determine presence or absence of grasses and graminoids (Curtis and McIntosh 1950, Dix 1958, Biondini et al. 1989). These presence/absence data were used to determine frequency (contacts per frame) of each grass and graminoid species, which was then used to produce a species ranking. Density of forbs and shrubs was converted to frequency to produce the same ranking.

Method: Line Point Intercept

A pin flag, approximately 1mm in diameter, was placed perpendicular to the ground at two meter intervals along the length of each transect (totaling 74 points per plot). All live plant species that touched the pin at any height were recorded, and the ground cover contacted by the point's tip was recorded. These contacts were averaged between the 74 points to produce an average frequency species ranking.

Statistical Analysis

Comparisons were made between methods within a single ecological site. Each method produced a list of species present on a plot (EXAMPLE: Table 1). This species list was sorted by frequency (line point intercept, and quadrat frame) or by average weight (clipping). This produced a relative species ranking for each method on each plot. No data transformations were required, as the data were compared within plots. The rankings produced by line point intercept and quadrat frequency frames were compared to those produced by clipping using the Mantel Test (Mantel 1967, Monte Carlo randomization, Relative Sorenson Distance). Standard diversity measurements (species richness, evenness, and Shannon Index diversity) were also calculated and compared between methods using a student's t-test (paired, two-tailed).

Table 1. Example of relative species abundance measure produced by each method on a loamy ecological site on the Dakota Prairie Grasslands in western North Dakota in 2012.

Plot ID	Species	Common	Line point: Proportion (0-1)	Clipping (g/m^2)	Quadrat Proportion (0-1)
NDSU188ESX11-5_L	ACHMIL	Western Yarrow	0	0	0.1429
	ANTMIC	Littleleaf Pussytoes	0	0	0.1429
	ARIPUR	Purple Threeawn	0	47.38	0.4286
	ARTFRI	Fringed Sagewort	0.0135	3.40	0.5
	BOUGRA	Blue Grama	0.0675	7.96	0.6429
	CALLON	Prairie Sandreed	0	6.7	0
	CARDUR	Needleleaf Sedge	0	0.71	0.1429
	CARFIL	Threadleaf Sedge	0.0541	4.45	0.7857
	HESCOM	Needle-and-Thread	0.2567	0.03	0.2857
	NASVIR	Green Needlegrass	0.0135	7.69	0.50
	PASSMI	Western Wheatgrass	0.2972	40.09	1.0
	PHLHOO	Hood's Phlox	0	0	0.2142
	POACOM	Canada Bluegrass	0	0	0.1429
	POAPRA	Kentucky Bluegrass	0	11.23	0.2857
	RATCOL	Prairie Coneflower	0.0270	0.63	0.2142
	SCHSCO	Little Bluestem	0	0	0.1429
	SPHCOC	Scarlet Globemallow	0	0	0.1429

Mantel Test Analysis

The Mantel method (Mantel 1967) "tests the significance of the correlation between matrices by evaluating results of repeated randomization" (McCune and Grace 2002). It is an alternative to regression analysis which avoids the problem of partial dependence within the matrix. This test was developed to examine clustering of diseases, but is versatile enough to be expanded to many applications, including community ecology. The Mantel Test uses a null hypothesis of no correlation between matrices (in this case species frequency rankings produced by different monitoring methods against clipping), comparing the relative distance between variables (species) rather than simply the species rankings produced. The test uses a randomization (Monte Carlo) approach to produce a standardized Mantel statistic (r) value between -1 and 1, with positive r values indicating positive correlation. A *p* value can be calculated from "the number of randomizations that yielded a test statistic equal to or more extreme than the observed value" (McCune and Grace 2002). We used an alpha value of 0.05 to indicate a statistically significant correlation between matrices.

RESULTS

Diversity Analysis

In order to explain and visualize possible differences between the methods, three standard diversity indices were calculated for each method on each plot (McCune and Mefford 2011). Species richness describes the total number of species found on each plot. Species evenness describes the relative population sizes of species within a plot. The Shannon index is a commonly used measure of biodiversity which incorporates both richness and evenness (Shannon 1948). These indices also provide a comparison of the depth of data provided by each monitoring method.

Loamy Ecological Site

The three methods produced different ($p \leq 0.05$) average values for richness, evenness, and Shannon Index diversity; with the exception of the line point intercept compared to clipping for Shannon Index (Table 2). On average, the quadrat frequency frame provided a greater number of plant species than the other methods.

Table 2. Standard diversity measurements calculated from each vegetation data collection method within the loamy ecological site. Shared superscript within diversity measurement type indicates no statistical difference (n=61, $p \leq 0.05$).

Loamy Ecological Site			
Diversity Measure	**Line Point Intercept**	**Clipping by Species**	**Quadrat Frequency**
Richness	11.00^a	13.40^b	18.50^c
Evenness	0.71^a	0.63^b	0.92^c
Shannon Index	1.65^a	1.59^a	2.61^b

Thin Loamy Ecological Site

The three methods produced different ($p \leq 0.05$) average values for richness, evenness, and Shannon Index diversity on the thin loamy ecological site, with the exception of line point intercept compared to clipping with Shannon Index (Table 3). On average, the quadrat frequency frame provided a greater number of plant species than the other methods.

Table 3. Standard diversity measurements calculated from each vegetation data collection method within the thin loamy ecological site. Shared superscript within diversity measurement type indicates no statistical difference (n=39, $p \leq 0.05$).

Thin Loamy Ecological Site			
Diversity Measure	**Line Point Intercept**	**Clipping by Species**	**Quadrat Frequency**
Richness	10.10^{a}	15.40^{b}	19.70^{c}
Evenness	0.72^{a}	0.64^{b}	0.92^{c}
Shannon Index	1.66^{a}	1.73^{a}	2.70^{b}

Loamy Ecological Site

Quadrat frequency frames and clipping by species produced a similar relative plant community ranking (H_0: no correlation between methods, r: 0.609, p=0.001) for the loamy ecological site. Line point intercept and clipping by species also produced a similar relative plant community ranking (r = 0.769, p=0.001). Nonmetric multidimensional scaling (NMS) was used to produce a visual representation of the Mantel Test results (Figure 1). The directional vectors in the graph connect the rankings produced by each method within a plot.

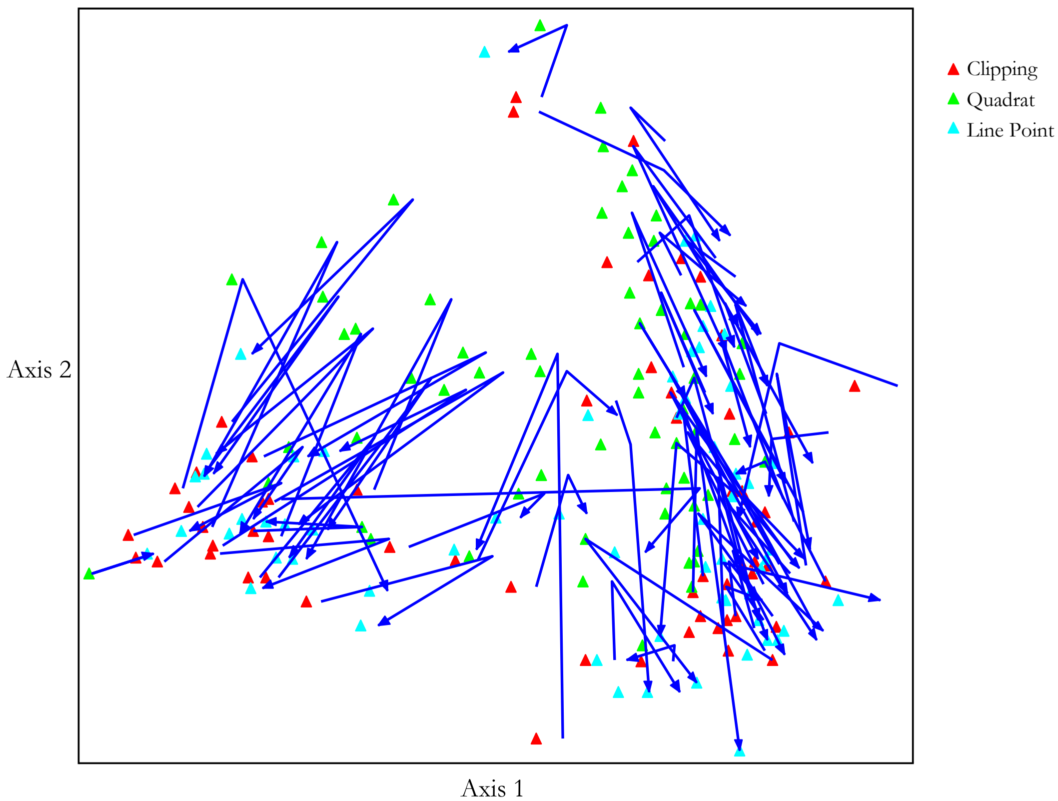

Figure 3. Nonmetric multidimensional scaling plot with directional vectors connecting results of the three vegetation data collection methods within a plot on the loamy ecological site in western North and South Dakota in 2012.

Thin Loamy Ecological Site

Quadrat frequency frames and clipping by species produced a similar relative plant community ranking (H_0: no correlation between methods, r = 0.719, *p*=0.001) for the thin loamy ecological site. Line point intercept and clipping by species also produced a similar relative plant community ranking (r: 0.819, *p*=0.001). Nonmetric multidimensional scaling was used to produce a visual representation of the Mantel Test results (Figure 2). The directional vectors in the graph connect the rankings produced by each method within a plot.

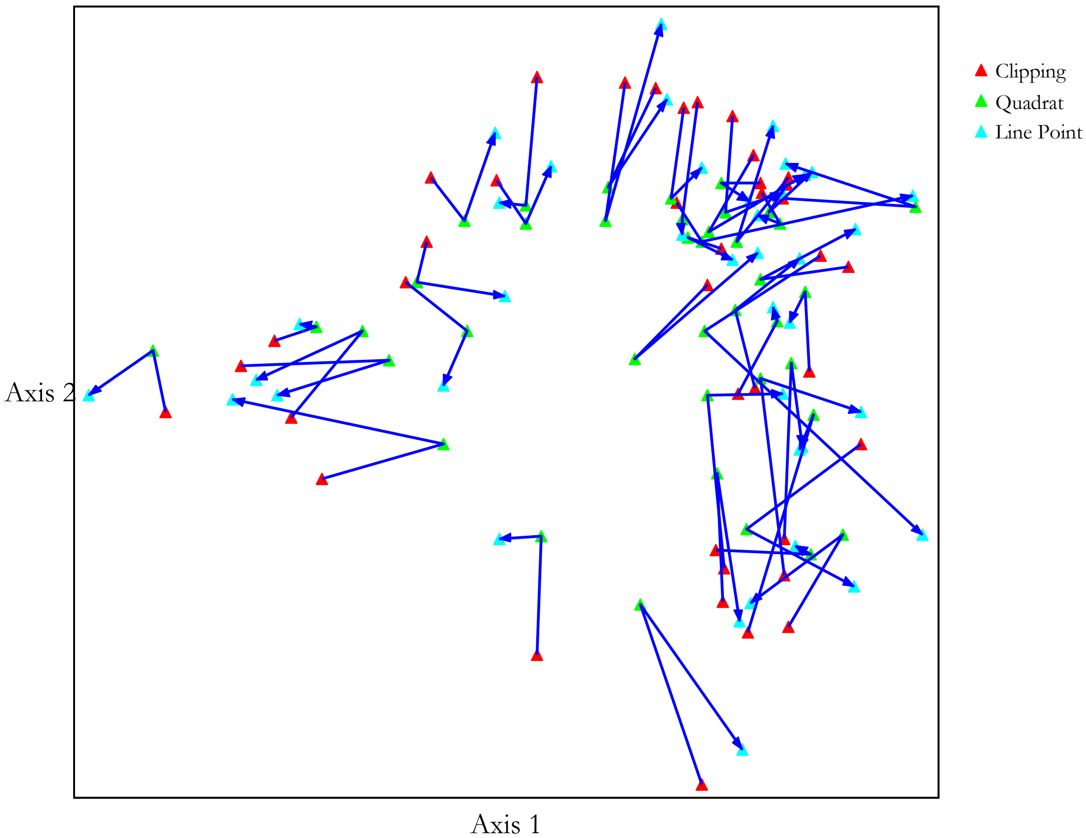

Figure 4. Nonmetric multidimensional scaling plot with directional vectors connecting results of the three vegetation data collection methods (1=Clipping, 2=Quadrat Frame, 3=Line Point Intercept) within a plot on the thin loamy ecological site in western North and South Dakota in 2012.

DISCUSSION

Diversity Analysis

The diversity analyses indicate that each method produces a statistically different result for commonly used diversity measurements. This is important if researchers or managers are using an indicator such as richness or diversity to make management decisions. In a case like this, whichever data collection method was used in a project, the same method should be used for all monitoring in order to avoid method bias.

Another important finding was the ability of the quadrat frequency frame to detect more species (i.e., higher richness values). This may seem intuitive due to the larger area covered by the frequency frame method when compared to clipping; however, clipping is still often chosen as a default monitoring method despite this disadvantage. Based on our findings, if detecting rare species or producing a complete species presence list is the goal, the quadrat frequency frame technique is the best method of the three. Stohlgren et al. (1998) also found that each of his methods (Daubenmire, Modified-Whittaker, large quadrat, and Parker) produced a different value for species richness, with the large quadrat (1.0 m^2) being the most cost efficient method.

Previous Comparisons

Few detailed comparisons of these methods have been done before. Prosser et al. (2003) compared a 0.25 m^2 quadrat frame to the U.S. Army Land Condition-Trend Analysis (LCTA) Program, which utilizes Line Point Intercept as a core method. They found that quadrat frequency frames better portrayed community diversity and species composition in a complex mixed grass prairie ecosystem. This finding agrees with our results when species richness is considered. Walker (1970) found that quadrat frequency frames were a simple to use procedure that provided useful data without an impractical time input, but West (1985) warned that managers should not attempt to calculate percent composition from frequency data, and Hironaka (1985) stated that other methods should be used in conjunction with quadrat frequency if time and money are available. Clark et al. (2008) compared the point intercept method with clipping in sagebrush steppe ecosystems and found point intercept as accurate as clipping but less time consuming, which agrees with our analysis.

Mantel Analysis

The findings of our Mantel test analysis show a strong correlation between the relative species rankings produced by the three monitoring methods. In all comparisons, this correlation was significant. This indicates that on loamy and thin loamy ecological sites in the northern Mixed-Grass Prairie, either of the less time-consuming methods (line point intercept and quadrat frequency frames), will produce the same relative species ranking as clipping by species.

When working on a landscape level, relative species rankings should prove adequate for making management decisions. These lists show which are dominant species, which are rare species, give an estimate of species richness, and provide information on relative proportions of desirable and undesirable species. There were differences in diversity index values produced by the three methods, but we believe that our similarity based analysis provides a more valuable tool for comparing rangeland sites. While the USDA-NRCS advocates using actual species weight (clipping by species) as a method for using similarity indices and state-transitional models (USDA-NRCS 1997), our results indicate that quadrat frequency frames and line point intercept have the potential to fit well with these models.

CONCLUSION

Relative species ranking, generated by quadrat frequency frames, is an efficient, cost-effective, and accurate way of monitoring mixed-grass prairie. We recommend that researchers and managers use careful consideration when choosing between rangeland monitoring methods. Too often we choose the most intensive method on the premise that it is also the best. We found that quadrat frequency frames and line point intercept produced the same ranking of species abundance as clipping, and did so with less time input. Quadrat frequency frames also produced a more complete survey of the species present on each plot. The quadrat frequency method has been criticized but we feel that the benefits of the method outweigh the possible limitations in many cases, especially when coupled with relative species ranking. Researchers and managers can often save time and money using these methods without sacrificing critical data quality. Our data also suggest that species abundance rankings could be used to compare previously surveyed sites. This has some promise for researchers needing to compare species composition on sites that were surveyed using different methodologies. This method of comparison needs further study to validate its use in different areas and ecosystems.

LITERATURE CITED

Ahmed, J., C.D. Bonham, and W.A. Laycock. 1983. Comparison of techniques used for adjusting biomass estimates by double sampling. *Journal of Range Management* 36: 217-221.

Archaux, F., L. Berges, and R. Chevalier. 2007. Are plant censuses carried out on small quadrats more reliable than on larger ones? *Plant Ecology* 188: 179-190.

Benkobi, L., D.W. Uresk, G.Schenbeck, and R.M. King. 2000. Protocol for monitoring standing crop in grasslands using visual obstruction. *Journal of Range Management* 53: 627-633.

Biondini, M.E., A.A. Steuter, and C.E. Grygiel. 1989. Seasonal fire effects on the diversity patterns, spatial distribution, and community structure of forbs in northern mixed prairie, USA. *Vegetatio* 85: 21-31.

Bonham, C.D. 1989. Measurements for terrestrial vegetation. John Wiley and Sons, New York. 338 p. ISBN: 0-471-04880-1.

Brummer, J.E., J.T. Nichols, R.K. Engel, and K.M. Eskridge. 1994. Efficiency of different quadrat sizes and shapes for sampling standing crop. *Journal of Range Management* 47: 84-89.

Cain, S.A. 1943. Sample-plot technique applied to alpine vegetation in Wyoming. *American Journal of Botany* 30: 230-247.

Clark, P.E, S.P. Hardegree, C.A. Moffet, and F.B. Pierson. 2008. Point sampling to stratify biomass variability in sagebrush steppe vegetation. *Rangeland Ecology & Management* 61: 614-622.

Clarke, K., M. Lewis, and B. Ostendorf. 2011. Additive portioning of rarefaction curves: Removing the influence of sampling on species diversity in vegetation surveys. *Ecological Indicators* 11: 132-139.

Curtis, J.T. and R.P. McIntosh. 1950. The interrelations of certain analytic and synthetic phytosociological characters. *Ecology* 31: 434-455.

Daubenmire, R. 1959. A canopy-coverage method of vegetation analysis. *Northwest Science* 33: 43-64.

DeBacker, M.D., J.S. Heywood, and L.W. Morrison. 2011. Optimized frequency measures for monitoring trends in tallgrass prairie. *Rangeland Ecology & Management*, 64(3):301-308.

Despain, D.W., P.R. Ogden, and E.L. Smith. 1991. Plant frequency sampling for monitoring rangelands. Some methods for monitoring rangelands and other natural area vegetation. *Extension Report 9043*. University of Arizona, Tucson, AZ.

Dix, R.L. 1958. Some slope-plant relationships in the grasslands of the Little Missouri Badlands of North Dakota. *Journal of Range Management* 11: 88-92.

Epstein, H.E., M.K. Raynolds, D.A. Walker, U.S. Bhatt, C.J. Tucker, and J.E. Pinzon. 2012. Dynamics of aboveground phytomass of the circumpolar Arctic tundra during the past three decades. *Environmental Research Letters* 7: 12 pp.

Everson, C.S. and G.P.Y. Clarke. 1987. A comparison of six methods of botanical analysis in the montane grasslands of Natale. *Vegetatio* 73: 47-51.

Floyd, D.A. and J.E. Anderson. 1987. A comparison of three methods for estimating plant cover. *Journal of Ecology* 75: 229-245.

Fream, W. 1888. The herbage of old grasslands. *The Journal of the Royal Agricultural Society of England* 24: 415-447.

Fream, W. 1890. The herbage of pastures. *The Journal of the Royal Agricultural Society of England* 1: 359-392.

Goodall, D.W. 1952. Some considerations in the use of point quadrants for the analysis of vegetation. *Australian Journal of Scientific Research Bulletin* 5. 41 pp.

Greig-Smith, P. 1983. Quantitative plant ecology. 3rd Ed. University of California Press, Berkeley and Los Angeles, CA.

Hanson, J.R., 1984. Bison ecology in the northern plains and a reconstruction of bison patterns for the North Dakota region. *Plains Anthropologist* 29: 93-113.

Havstad, K.M., D.C. Peters, R.Skaggs, J. Brown, B. Bestelmeyer, E. Fredrickson, J. Herrick, J. Wright. 2007. Ecological services to and from rangelands of the United States. *Ecological Economics* 64: 261-268.

Heady, H.F. 1957. The measurement and value of plant height in the study of herbaceous vegetation. *Ecology* 38: 313-320.

Heady, H.F., and L. Rader. 1958. Modifications of the point frame. *Journal of Range Management* 11: 95-96.

Hironaka, M. 1985. Frequency approaches to monitor rangeland vegetation. Symp. on use of frequency and density for rangeland monitoring. William C. Krueger, Chairman. Proc. 38th Annual Meeting, Soc. for Range Manage. Feb. 1985. Salt Lake City. Soc. for Range Manage. 84-86

Kennedy, K.A. and P.A. Addison. 1987. Some considerations for the use of visual estimates of plant cover in biomonitoring. *Journal of Ecology* 75: 151-157.

Levy, E.B., and E.A. Madden. 1933. The point method for pasture analysis. *New Zealand Journal of Agriculture* 46: 267-279.

Lopez, R. D., and M.B. Fennessy. 2002. Testing the floristic quality assessment index as an indicator of wetland condition. *Ecological Applications* 12: 487-497.

Mantel, N. 1967. The detection of disease clustering and generalized regression approach. *Cancer Research* 27: 209-220.

McCune, B. and M. J. Mefford. 2011. PC-ORD. Multivariate Analysis of Ecological Data. Version 6. MjM Software, Gleneden Beach, Oregon, U.S.A

McCune, B. and J. B. Grace. 2002. Analysis of Ecological Communities. MjM Software, Gleneden Beach, Oregon, USA (www.pcord.com) 304 pages. With a contribution by Dean L. Urban.

Mosley, J.C., S.C. Bunting, and M. Hironaka. 1989. Quadrat and sample sizes for frequency sampling mountain meadow vegetation. *The Great Basin Naturalist* 49: 241-248.

Nerney, N.J. 1960. A modification of the point-frame method of sampling range vegetation. *Journal of Range Management* 13: 261-262.

Priestly, J.H. 1913. The quadrat as a method for the field excursion. *Journal of Ecology* 1: 89-94.

Prosser, C.W., K.M. Skinner, and K.K. Sedivec. 2003. Comparison of 2 techniques for monitoring vegetation on military lands. *Journal of Range Management* 56: 446-454.

Ramsey, F. 1916. Quadrat studies in a mountain grassland. *Botanical Gazette* 62: 70-74.

Roberts, R.A. 1933. The percentage productivity method. *In:* Methods of pasture analysis VIII. *Agricultural Progress* 10: 246-249.

Sampson, A.W. 1917. Succession as a factor in range management. *Journal of Forestry* 15: 593-596.

Sedivec. K.K. and J.L Printz. 2012. Ecological sites of North Dakota. North Dakota State University Extension Service Publication R-1556.

Shannon, C.E. 1948. A mathematical theory of communication. *Bell System Technical Journal* 27: 379–423.

Smith, J.G. 1959. Additional modifications of the point frame. *Journal of Range Management* 12: 204-205.

Stapleton, R.G. 1913. Pasture problems. Drought resistance. *Journal of Agricultural Science* 5: 129-151.

Stohlgren, T.J., K.A. Bull, Y. Otsuki. 1998. Comparison of Rangeland Vegetation Sampling Techniques in the Central Grasslands. *Journal of Range Management*. Vol. 51: 164-172.

Thoma, D.P., D.W. Bailey, D.S. Long, G.A. Nielsen, M.P. Henry, M. C. Breneman, and C. Montagne. 2002. Short-term monitoring of rangeland forage conditions with AVHRR imagery. *Journal of Range Management* 55: 383-389.

United States Department of Agriculture, Natural Resource Conservation Service. 1997. National Range and Pasture Handbook.

United States Department of Agriculture, Natural Resources Conservation Service. 2003. Loamy Ecological Site Description. MLRA 54. Section II FOTG.

United States Department of Agriculture, Natural Resources Conservation Service. 2003. Thin Loamy Ecological Site Description. MLRA 54. Section II FOTG.

United States Department of Agriculture, Natural Resources Conservation Service. 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296.

Uresk, D.W., and D.E. Mergen. 2012. Monitoring mid-grass prairie in southwestern South Dakota and northwestern Nebraska, USA. *Grassland Science* 58: 140-146.

Walker, B.H. An evaluation of eight methods of botanical analysis on grasslands in Rhodesia. *Journal of Applied Ecology* 7: 403-416.

Weaver, J.E., and F.E. Clements. 1929. Plant Ecology. New York, NY, USA: Mcgraw-Hill Book Company, Inc. 520 p.

Wells, P.V. 1970. Historical factors controlling vegetational patterns and floristic distribution in the Central Plains Region of North America. In Pleistocene and Recent Environments of the Central Great Plains. D. Wakefield Jr. and K.J. Jones Jr., eds. p 211-221. Special Publication 3. The University Press Kansas, Lawrence.

West, N.E. 1985. Shortcomings of plant frequency-based methods for range condition and trend. William C. Krueger, Chairman. Proc., 38th Annual Meeting Soc. for Range

Manage. Feb. 1985. Salt Lake City. Soc. for Range Manage. 87-90.

Whitman, W.C. and E.I. Siggeirson. 1954. Comparison of line interception and point contact methods in the analyses of mixed grass range vegetation. *Ecology* 35: 431-436.

Wiegert, R.G. 1962. The selection of an optimum quadrat size for sampling the standing crop of grasses and forbs. *Ecology* 43: 125-129.

Williams, R.E., B.E. Allred, R.M. Denio, and H.A. Paulsen. 1968. Conservation, development, and use of the world's rangeland. *Journal of Range Management*. 21:355–360.

Wilson, J.W. 1960. Inclined point quadrats. *New Phytologist* 59: 1-8.

APPENDIX A: PLANT SPECIES OCCURRING ON LOAMY ECOLOGICAL SITE PLOTS IN 2012 (130 SPP.)

Achillea millefolium	Western Yarrow	***Cirsium undulata***	Wavyleaf Thistle
Agropyron cristatum	Crested Wheatgrass	***Comata umbellata***	Bastard Toadflax
Allium textile	Textile Onion	***Convovulvis arvensis***	Field Bindweed
Andropogon gerardii	Big Bluestem	***Coryphantha vivipara***	Spinystar
Anemone cylindrica	Candle Anemone	***Crepis acuminata***	Tapertip Hawksbeard
Antennaria microcephala	Littleleaf Pussytoes	***Dalea purpurea***	Purple Prairie Clover
Antennaria neglecta	Field Pussytoes	***Dasiphora fruticosa***	Shrubby Cinquefoil
Antennaria parvifolia	Small-Leaf Pussytoes	***Descurainia sophioides***	Northern Tansymustard
Aristida longespica	Slimspike Threeawn	***Dichanthelium oligosanthes***	Scribner's Rosette Grass
Aristida purpurea	Purple Threeawn	***Dichanthelium wilcoxianum***	Fall Rosettegrass
Arnica fulgens	Foothill Arnica	***Distichlis spicat***	Inland Saltgrass
Artemisia canadensis	Silver Sagebrush	***Dodecatheon pulchellum***	Darkthroat Shootingstar
Artemisia dracunculoides	Green Sagewort	***Echinacea angustifolia***	Black Samson
Artemisia frigida	Fringed Sagewort	***Elymus lanceolatus***	Thickspike Wheatgrass
Artemisia ludoviciana	White Sagewort	***Elymus trachycaulus***	Slender Wheatgrass
Artemisia tridentata	Big Sagebrush	***Erigeron bellidiastrum***	Daisy Fleabane
Asclepias pumilla	Plains Milkweed	***Eriogonum flavum***	Alpine Golden Buckwheat
Astragalus agrestis	Purple Milkvetch	***Erigeron strigosus***	Prairie Fleabane
Astragalus laxmannii	Prairie Milkvetch	***Escobaria vivipara***	Spinystar
Astragalus missouriensis	Missouri Milkvetch	***Euphorbia esula***	Leafy Spurge
Atriplex nuttalli	Nuttall's Saltbush	***Galium boreale***	Northern Bedstraw
Bouteloua curtipendula	Sideoats Grama	***Gaura coccinea***	Scarlet Beeblossom
Bouteloua gracilis	Blue Grama	***Geum triflorum***	Prairie Smoke
Bromus arvensis	Field Brome	***Grindelia squarrosa***	Curlycup Gumweed
Bromus inermis	Smooth Brome	***Gutierrezia sarothrae***	Broom Snakeweed
Bromus tectorum	Cheatgrass	***Hedeoma hispida***	False Pennyroyal
Buchloe dactyloides	Buffalograss	***Helianthus pauciflora***	Stiff Sunflower
Calamovilfa longifolia	Prairie Sandreed	***Hesperostipa comata***	Needle-and-Thread
Calamagrostis montanensis	Plains Reedgrass	***Hesperostipa spartina***	Porcupinegrass
Campanula rotundifolia	Bluebell Bellflower	***Heterotheca villosa***	Hairy False Goldenaster
Carex duriuscula	Needleleaf Sedge	***Juncus horizontalis***	Creeping Juniper
Carex filifolia	Threadleaf Sedge	***Koeleria macrantha***	Prairie Junegrass
Carex inops	Sun Sedge	***Krascheninnikovia lanata***	Winterfat
Cerastium arvense	Field Chickweed	***Lactuca tatarica***	Blue Lettuce
Cirsium arvense	Canada Thistle	***Lesquerella arenosa***	Great Plains Bladderpod
Cirsium flodmanii	Flodman's Thistle		

Liatris punctata	Dotted Blazingstar
Linus lewisii	Prairie Flax
Lithospermum incisum	Narrowleaf Stoneseed
Lygodesmia juncea	Rush Skeletonplant
Machaeranthera pinnatifida	Lacy Tansyaster
Medicago lupulina	Black Medick
Medicago sativa	Alfalfa
Melilotus officinalis	Yellow Sweetclover
Monarda fistulosa	Wild Bergamot
Muhlenbergia cuspidata	Plains Muhly
Nassella viridula	Green Needlegrass
Oligoneuron album	Prairie Goldenrod
Oligoneuron rigidum	Stiff Goldenrod
Opuntia fragilis	Brittle Pricklypear
Opuntia polyacantha	Plains Pricklypear
Oxytropis lambertii	Lambert's Crazyweed
Pascopyrum smithii	Western Wheatgrass
Pediomelum aromaticum	Silverleaf Scurfpea
Pediomelum esculentum	Indian Breadroot
Phlox hoodii	Hood's Phlox
Plantago patagonia	Wooly Plantain
Poa compressa	Canada Bluegrass
Poa pratensis	Kentucky Bluegrass
Poa secunda	Sandberg Bluegrass
Polygala alba	White Milkwort
Polygonum douglasii	Douglas' Knotweed
Portulaca species	Purslane Species
Potentilla effusa	Branched Cinquefoil
Potentilla pensylvanica	Pennsylvania Cinquefoil
Potentilla pulchella	Pretty Cinquefoil
Prunus virginianus	Chokecherry
Pulsatilla patens	Pasquflower
Punctelia species	Punctelia
Ratibita columnifera	Prairie Coneflower
Rhus trilobata	Skunkbush Sumac
Rosa arkana	Prairie Rose
Schedonnardus paniculatus	Tumblegrass
Schizachirium scoparium	Little Bluestem
Selaginella densa	Clubmoss
Shepherdia argentea	Silver Buffaloberry
Sisyrinchium montanum	Strict Blue-eyed Grass
Solidago missouriensis	Missouri Goldenrod
Solidago mollismus	Velvety Goldenrod
Spharalcea coccinea	Scarlet Globemallow
Sporobolus cryptandrus	Sand Dropseed
Sporobolus heterolepis	Prairie Dropseed
Symphyotrichum ericoides	White Heath Aster
Symphyotrichum falcatum	White Prairie Aster
Symphyotrichum laeve	Smooth Blue Aster
Symphyotrichum oblongifolia	Aromatic Aster
Symphoricarpos occidentalis	Western Snowberry
Taraxacum officinale	Dandelion
Tetraneuris acaulis	Stemless Four-Nerve Daisy
Thermopsis gracilis	Slender Goldenbanner
Thinopyrum intermedium	Intermediate Wheatgrass
Tragopogon dubius	Goatsbeard
Vicia americana	American Vetch
Viola nuttallii	Nuttall's Violet
Vulpia octoflora	Sixweeks Fescue

APPENDIX B: PLANT SPECIES OCCURRING ON THIN LOAMY ECOLOGICAL SITE PLOTS IN 2012 (143 SPP.)

Achillea millefolium	Western Yarrow	***Campanula rotundifolia***	Bluebell Bellflower
Agropyron cristatum	Crested Wheatgrass	***Carex duriuscula***	Needleleaf Sedge
Allium textile	White Wild Onion	***Carex filifolia***	Threadleaf Sedge
Amorphis canadensis	Leadplant	***Carex inops***	Sun Sedge
Andropogon gerardii	Big Bluestem	***Carex sprengelii***	Sprengel's Sedge
Anemone canadensis	Canadian Anemone	***Cerastium arvense***	Field Chickweed
Anemone cylindrica	Candle Anemone	***Cirsium flodmanii***	Flodman's Thistle
Antennaria microcephala	Littleleaf Pussytoes	***Cirsium undulata***	Wavyleaf Thistle
Antennaria neglecta	Field Pussytoes	***Comata umbellata***	Bastard Toadflax
Antennaria parvifolia	Small-Leaf Pussytoes	***Convovulvis arvensis***	Field Bindweed
Aristida purpurea	Purple Threeawn	***Conysa canadensis***	Canadian Horseweed
Arnica fulgens	Foothill Arnica	***Dalea purpurea***	Purple Prairie Clover
Artemisia canadensis	Silver Sagebrush	***Dasiphora fruticosa***	Shrubby Cinquefoil
Artemisia dracunculoides	Green Sagewort	***Dichanthelium leibergii***	Leiberg's Panicum
Artemisia frigida	Fringed Sagewort	***Dichanthelium oligosanthes***	Scribner's Rosette Grass
Artemisia ludoviciana	White Sagewort	***Distichlis spicata***	Inland Saltgrass
Artemisia tridentata	Big Sagebrush	***Dodecatheon pulchellum***	Darkthroat Shootingstar
Asclepias pumilla	Plains Milkweed	***Echinacea angustifolia***	Black Samson
Asclepias verticillata	Whorled Milkweed	***Elymus lanceolatus***	Thickspike Wheatgrass
Astragalus agrestis	Purple Milkvetch	***Elymus repens***	Quackgrass
Astragalus americanus	American Milkvetch	***Elymus trachycaulus***	Slender Wheatgrass
Astragalus gilviflorus	Plains Milkvetch	***Eriogonum flavum***	Alpine Golden Buckwheat
Astragalus laxmannii	Prairie Milkvetch	***Erigeron strigosus***	Prairie Fleabane
Astragalus missouriensis	Missouri Milkvetch	***Escobaria vivipara***	Spinystar
Atriplex nuttalli	Nuttall's Saltbush	***Euphorbia esula***	Leafy Spurge
Balsamorhiza sagittata	Arrowleaf Balsamroot	***Galium boreale***	Northern Bedstraw
Bouteloua curtipendula	Sideoats Grama	***Gaura coccinea***	Scarlet Beeblossom
Bouteloua gracilis	Blue Grama	***Geum triflorum***	Prairie Smoke
Bouteloua hirsuta	Hairy Grama	***Glycyrrhiza lepidota***	American Licorice
Bromus arvensis	Field Brome	***Grindelia squarrosa***	Curlycup Gumweed
Bromus inermis	Smooth Brome	***Gutierrezia sarothrae***	Broom Snakeweed
Bromus tectorum	Cheatgrass	***Hedeoma hispida***	False Pennyroyal
Buchloe dactyloides	Buffalograss	***Helianthus pauciflora***	Stiff Sunflower
Buglossoides arvensis	Corn Gromwell	***Hesperostipa comata***	Needle-and-Thread
Calamovilfa longifolia	Prairie Sandreed	***Hesperostipa spartina***	Porcupinegrass
Calamagrostis montanensis	Plains Reedgrass	***Heterotheca villosa***	Hairy False Goldenaster
Calystegia sericata	False Bindweed	***Juniperus communis***	Common Juniper

Juniperus horizontalis	Creeping Juniper
Juniperus scopulorum	Rocky Mountain Juniper
Koeleria macrantha	Prairie Junegrass
Krascheninnikovia lanata	Winterfat
Lactuca tatarica	Blue Lettuce
Liatris punctata	Dotted Blazingstar
Linus lewisii	Prairie Flax
Lithospermum canescens	Hoary Puccoon
Lithospermum incisum	Narrowleaf Stoneseed
Lomatium foeniculaceum	Biscuitroot
Lygodesmia juncea	Rush Skeletonweed
Medicago sativa	Alfalfa
Melilotus officinalis	Yellow Sweetclover
Monarda fistulosa	Wild Bergamot
Muhlenbergia cuspidata	Plains Muhly
Nassella viridula	Green Needlegrass
Oenothera flava	Yellow Evening Primrose
Oligoneuron album	Prairie Goldenrod
Oligoneuron rigidum	Stiff Goldenrod
Opuntia fragilis	Brittle Pricklypear
Opuntia polyacantha	Plains Pricklypear
Oxytropis lambertii	Purple Locoweed
Pascopyrum smithii	Western Wheatgrass
Pediomelum argophyllum	Silverleaf Scurfpea
Pediomelum esculentum	Indian Breadroot
Penstemon angustifolius	Beardtongue
Penstemon glaber	Sawsepal Penstemon
Phlox hoodii	Hood's Phlox
Plantago patagonia	Wooly Plantain
Poa compressa	Canada Bluegrass
Poa pratensis	Kentucky Bluegrass
Poa secunda	Sandberg Bluegrass
Polygala alba	White Milkwort
Potentilla effusa	Branched Cinquefoil
Potentilla hippiana	Wooly Cinquefoil

Potentilla pensylvanica	Pennsylvania Cinquefoil
Prunus virginiana	Chokecherry
Pulsatilla patens	Cutleaf Anemone
Ratibita columnifera	Prairie Coneflower
Rhus trilobata	Skunkbrush Sumac
Rosa arkana	Prairie Rose
Schizachirium scoparium	Little Bluestem
Selaginella densa	Clubmoss
Senecio spp.	Ragwort
Shepherdia argentea	Silver Buffaloberry
Sisyrinchium montanum	Strict Blue-eyed Grass
Solidago missouriensis	Missouri Goldenrod
Solidago mollismus	Velvety Goldenrod
Solidago nemoralis	Gray Goldenrod
Solidago speciosa	Showy Goldenrod
Spartina pectinata	Prairie Cordgrass
Spharalcea coccinea	Scarlet Globemallow
Sporobolus cryptandrus	Sand Dropseed
Sporobolus heterolepis	Prairie Dropseed
Symphyotrichum ciliolatum	Alkali Aster
Symphyotrichum ericoides	White Heath Aster
Symphyotrichum falcatum	White Prairie Aster
Symphyotrichum laeve	Smooth Blue Aster
Symphyotrichum oblongifolia	Aromatic Aster
Symphoricarpos occidentalis	Western Snowberry
Taraxacum officinale	Dandelion
Tetraneuris acaulis	Stemless Four-Nerve Daisy
Thinopyrum intermedium	Intermediate Wheatgrass
Toxicodendron rydbergii	Poison Ivy
Tragopogon dubius	Goatsbeard
Vicia americana	American Vetch
Viola pedatifida	Prairie Violet
Yucca glauca	Soapweed Yucca
Zizia aptera	Meadow Zizia

APPENDIX C: LITTLE MISSOURI NATIONAL GRASSLAND ALLOTMENTS USED FOR ANALYSIS FROM DATA COLLECTED IN 2012

Loamy Ecological Site	
Allotment	**Plots Used**
1	1
13	1
37	2
43	2
51	3
53	3
54	2
58	1
69	1
84	2
108	2
120	1
165	2
166	1
175	1
186	2
188	2
190	1
191	1
202	2
273	5
275	1
370	1
371	3
374	2
376	2
405	1
407	1
408	2
409	1
411	2
412	2
512	5

Thin Loamy Ecological Site	
Allotment	**Plots Used**
1	1
27	1
33	1
37	2
53	2
54	3
69	2
108	3
109	1
115	1
165	1
166	5
169	5
186	2
188	2
190	2
202	1
273	4