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A MEASUREMENT OF HISTORICAL AND CONTEMPORARY FUNCTIONAL DIVERSITY ON THE MONAHAN RECLAIMED GRASSLAND

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A MEASUREMENT OF HISTORICAL AND CONTEMPORARY FUNCTIONAL DIVERSITY ON THE MONAHAN RECLAIMED GRASSLAND

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A MEASUREMENT OF HISTORICAL AND CONTEMPORARY FUNCTIONAL DIVERSITY ON THE MONAHAN RECLAIMED GRASSLAND

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A MEASUREMENT OF HISTORICAL AND CONTEMPORARY FUNCTIONAL DIVERSITY ON THE MONAHAN RECLAIMED GRASSLAND

An Abstract of the Thesis by
Jacob A. Heil

In 1984 a portion of the Monahan, a PSU Biology field site, was reclaimed to establish a native grassland community and to prevent runoff of acidic groundwater. In the years since then, several student projects have analyzed the vegetation community on the site, estimating the biodiversity found there. In this study, conducted in 2014, the biodiversity of the Monahan was measured using four indices of functional diversity. Functional diversity describes the variety of ecological functions in a community; functional diversity indices measure and describe these functions instead of individual species. Results from two past graduate theses were compared to the 2014 findings. This comparison showed that the Monahan reclaimed grassland had generally increased in functional diversity (and by extension biodiversity) over time, but the dominant facets of diversity have been variable in each sample. In the first samples taken after the reclamation (Vickers, 1989) the community became more functionally even and divergent; that is, the species found were evenly spread across the community's functional groups. A sample taken in 1994 revealed that the grassland had become less functionally even and divergent but more functionally dispersed, or were more widely spread across the functional groups (Yates, 1996). The survey conducted for this thesis in 2014 revealed that the grassland is at the highest level of functional richness ever recorded, but is less functionally diverse than 1994 by all other indices. Overall, since the

initial 1984 reclamation, the grassland has actually increased in all areas of functional diversity.

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CHAPTER I

INTRODUCTION

The Sampling Site

This study was conducted at the Monahan Outdoor Education Center (Figure 1), a tract of land owned by the Pittsburg State University Biology Department. The Monahan is located in Crawford County, KS, about one mile to the northeast of the town Cherokee, KS. Uses of the Monahan include education, research, and recreation among others.

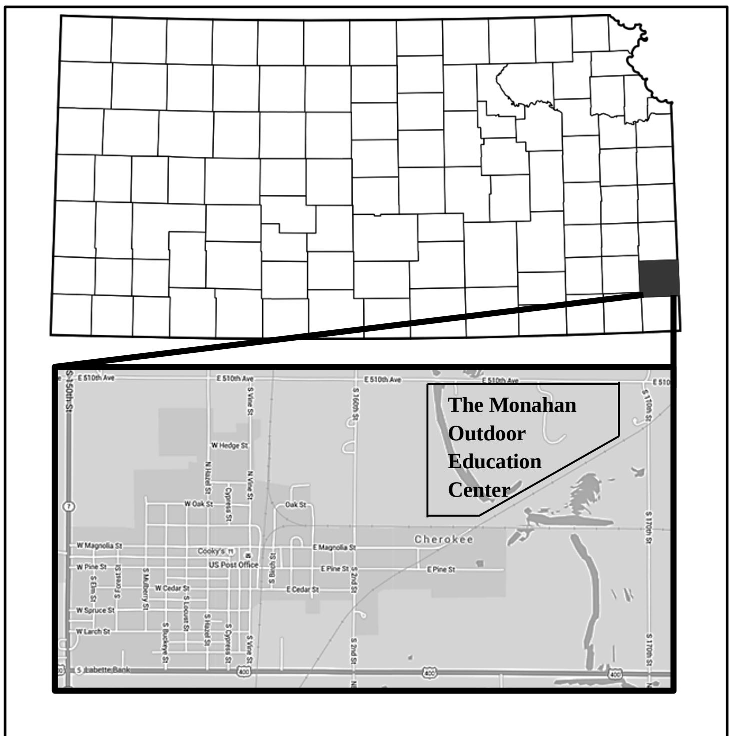

Figure 1. Location of the Monahan Outdoor Education Center. Retrieved from www.google.com/maps on 1/6/2016.

In the late 1800s and early 1900s the Monahan was owned by coal mining companies that conducted both underground and surface mining operations (Vickers, 1989). Eventually it was home to a coal processing plant that operated until the mid-1940s. The coal processing plant produced waste that was heaped in “gob piles” on the site. The gob piles were composed of mostly pyrite (FeS_2), a chemical that reacts with oxygen resulting in acidic products (Imhof, 1994). As a result, the Monahan became a barren, toxic waste site with the potential to produce acidic runoff and groundwater.

In 1984, after many years of political and social pressure, the Office of Surface Mining and the Soil Conservation Service collaborated to reclaim the Monahan site (Imhof, 1994). Reclamation (or restoration) is “the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems” (Jackson et al., 1995). Purposes of reclamations vary by situation, however, they are generally conducted with the intention of “increasing the natural value of a disturbed site or improving the ecosystem so that is productive and does not affect the area around it through erosion and other natural processes” (Prach and Hobbs, 2008). The Monahan reclamation was motivated by the necessity to prevent erosion of soils and runoff from rain or acidic groundwater (Vickers, 1989). The specific steps of the reclamation are detailed in the theses of Vickers (1989) and Yates (1996). The reclamation culminated with the seeding of a set of mostly native plants in order to establish a community that was similar to natural Kansas grasslands (Table 1).

Table 1. Species originally seeded as part of the 1984-85 reclamation of the Monahan. (Vickers, 1989)

Species	Common Name
Pascopyrum smithii	Western Wheatgrass
Andropogon gerardii	Big Bluestem
Bouteloua curtipendula	Sideoats Grama
Bouteloua dactyloides	Buffalo Grass
Panicum virgatum	Switchgrass
Schizachyrium scoparium	Little Bluestem
Sorghastrum nutans	Indiangrass
Dalea purpurea	Purple Prairie Clover
Helianthus maximiliani	Maximilian Sunflower
Ratibida pinnata	Grayhead Prairie Clover
Elaeagnus umbellata	Autumn Olive
Prunus americana	American Plum
Prunus serotina	Wild Cherry
Rhus aromatica	Aromatic Sumac
Juglans nigra	Black Walnut
Quercus macrocarpa	Pin Oak
Quercus palustris	Bur Oak
Pinus negra	Austrian Pine
Pinus taeda	Loblolly Pine
species unknown	Hackberry
species unknown	Mulberry

Three graduate theses have addressed the development of the plant community following the Monahan reclamation. In 1989 Jeff L. Vickers evaluated the re-vegetation of the Monahan by sampling the plants of the reclaimed grassland and comparing to the original seeding. His data provided insight into the performance of plant species on the Monahan since the original seeding and he hoped to establish a base of knowledge which could be built on by future studies. His thesis also includes a thorough treatment of the history of the Monahan and the process of reclamation used.

The next graduate thesis was conducted by Sally Ann Imhof and finalized in 1994. The purpose of her research was to study the water quality and physical integrity of the Monahan. In her introduction, Imhof provides a comprehensive history of the Monahan including technical detail on soil conditions prior to the reclamation. Imhof found that the Monahan was structurally sound and aesthetically pleasing; however, the research revealed that water on site was highly acidic, as was runoff coming from the Monahan.

In 1996 Karen F. Yates compared the ability of two different multivariate statistical techniques (classification and ordination) to detect sub-communities of plants on the Monahan. Yates found that the Monahan was a “largely homogenous grassland community” and was dominated by the species *Panicum virgatum* (Switchgrass). Her analysis of the ordination techniques “TWINSPAN” and “DEFAULT-CCA” revealed that TWINSPAN provided a more informative analysis of the grassland; however, no distinct sub-communities of plants were found.

Today the Monahan has a varied ecology with a mosaic of grassland, wetland, woods, and strip pit lakes. It is used by PSU classes and students, as well as community members. In 2014 (the year that the survey for this study was conducted) it had been 20 years since the vegetation on the Monahan had been surveyed or analyzed. One purpose of this study is to evaluate the biodiversity of the reclaimed grassland on the Monahan and compare it to the historical data collected by Vickers (1989) and Yates (1996).

Biodiversity

To better understand the development of the Monahan reclaimed grassland both now and through its history, it is important to understand its biodiversity. Biodiversity has been defined as: “Species, genetic, and ecosystem diversity in an area, sometimes including associated abiotic components," (Swingland, 2000). Biodiversity is understood to be an important factor in the functioning of an ecosystem (Gobold & Solan, 2009). Increases in biodiversity have been linked to increased productivity (Marquard et al., 2009), stability (Tilman et al., 2006; Dovciak and Halpern, 2010), reliability (Naeem and Li, 1997), and resilience to change and catastrophe (Downing et al., 2012). These studies and others like them suggest that an overall increase in biodiversity on the Monahan throughout the time since its reclamation would indicate an increasingly healthy plant community.

The purpose of this study is to evaluate the biodiversity on the Monahan in such a way that both of the past studies can be compared to the current Monahan grassland. This comparison will provide a sound analysis of the trends in biodiversity on the Monahan grassland throughout its existence. The essential question that arises is: How can changes in biodiversity on the Monahan grassland be measured and calculated?

Some historical data and analysis exists concerning biodiversity on the Monahan. The theses of Vickers (1989) and Yates (1996) both evaluated the biodiversity of the Monahan. Vickers examined species richness, abundance, and the establishment of different types of plants on the Monahan since reclamation. Vickers established a base of information for future studies to build from. Considerably more complex, Yates's approach was centered on the concepts of classification (grouping of samples by similarity) and ordination (analysis of species abundance along environmental gradients). A thorough treatment of these concepts can be found in her graduate thesis.

Differences in methods for measurement of biodiversity have been present in Ecology for quite some time (Hurlbert, 1971; Grime, 1997; Purvis and Hector, 2000;

Spash and Aslaksen, 2015). Many different indexes have been proposed and considered throughout the past several decades in order to quantify and represent biodiversity. Methods of measurement are numerous and highly diversified, but can be classified based on similar philosophies; some categories of measurement include species diversity, phylogenetic diversity, functional diversity among others (Hurlbert, 1971; Faith, 1992; Tilman et al., 1997; Diaz and Cabido, 2001; Petchey and Gaston, 2002). It is important to understand the philosophy behind any approach to measuring biodiversity in order to understand the nature of its results. For the purposes of this study (and for brevity), the distinction between just two measurement types will be highlighted.

Species diversity is a strategy of measuring biodiversity mainly from species richness. (Mace et al., 2012) Species diversity has been measured many different ways (Hurlbert, 1971). Two simple components of species diversity are species richness (number of species) and species evenness (comparative abundance of species). The essential contention of species diversity is that higher numbers of species in a community equate to a higher level of production, resilience, stability, etc. (Keesing et al., 2006). While species richness is a relatively simple measure of diversity in a community, its effectiveness as a method of measuring biodiversity has been criticized (Hurlbert, 1971; Gagic et al., 2015). The thrust of the arguments against species diversity is that it is too simplistic, and that individual species must be examined in order to determine the differences between species and how they affect an ecosystem, as opposed to their raw numbers or abundance.

Another method of measuring biodiversity is functional diversity. Functional diversity (FD) is a measure of biodiversity that “generally involves understanding communities and ecosystems based on what organisms do, rather than on their evolutionary history [species identity]," (Petchey & Gaston, 2006). Essentially FD measurement is the quantification of the functional traits that individual species have, how they affect the ecosystem, and the diversity of these traits within the community. Proponents of functional diversity argue that their studies have shown it to be a more effective indicator of community health than other forms of measurement (Diaz and Cabido, 2001; Gagic et al., 2015; Leduc et al., 2015). One of the main critiques of functional diversity is its lack of unity and clarity in practice (Petchey and Gaston, 2002). Much like the general topic of biodiversity, debate and diversification have arisen in the discussion of FD. Many indexes have been proposed for the measurement of functional diversity, resulting in calls for unification of the practice (Petchey and Gaston, 2006; Villeger et al. 2008).

Any approach to the analysis of historical biodiversity on the Monahan needed to be applicable to the data provided in the theses of Vickers and Yates. In both of these studies lists of species and their abundance were included. Species richness and evenness can be easily derived from this data. These two measurements provided a solid foundation for the historical analysis of the Monahan grassland. An index of functional diversity was chosen that was compatible with their data, so that the past graduate studies could be compared to this study.

The Measurement of Functional Diversity

Mason et al. (2003) and Ricotta (2005) attempted to unify FD by arguing that certain primary components and criteria must be achieved in order for an FD index to be useful. Villeger et al. (2008) applied several indexes to the criteria of Mason et al. (2003) and Ricotta (2005), but they were unable to isolate an index that successfully met all the criteria. As a result, Villeger et al. (2008) proposed an approach to FD that separated FD into three distinct indexes: functional richness, functional evenness, and functional divergence. Alone, none of the three indexes met the criteria for an FD index; however, together the three indexes encompassed all of the criteria deemed necessary by Mason et al. and Riccota. Laliberte and Legendre (2010) built on this index by adding a fourth index, functional dispersion. Thorough treatments of all indexes can be found in their respective papers.

Prior to the calculation of these indexes, a set of functional traits must be identified to characterize the community. "'Functional traits" are defined as morpho-physio-phenological traits which impact fitness indirectly via their effects on growth, reproduction and survival'" (Violle et al., 2007). Theoretically, as the number of functional traits included increases, so does the comprehensiveness of the study. Due to the intricacy of all organisms, possible measureable functional traits are all but endless. One limiting factor for traits to be useable by the indexes of Villeger et al. (2008) and Laliberte and Legendre (2010) is that they must be quantitative as opposed to qualitative. Quantitative traits are traits that can be represented by a quantity (e.g. the height of a plant). Qualitative traits are represented by a quality (e.g. the color of a plant). Cornelissen et al. (2003) compiled a list of plant traits, their functions in the ecosystem, and instructions for their measurement. The number of traits measured (n) will vary based on available data, but these indexes can theoretically be computed using any number of traits.

Functional Richness is the volume occupied by a community in *n*-dimensional trait space (Villeger et al., 2008). Each species in a sample is assigned values for each functional trait (*t*) measured. Any given species (*s*) possesses coordinates in functional trait space that are the values of its traits (t_1, t_2, t_3,…t_n). Plotted together, the measured traits of all species in a community define its functional trait space. The volume of functional trait space is computed using the Quickhull algorithm (Barber et al., 1996). This index represents biodiversity as the amount of trait space occupied by a community; a higher functional richness indicates a more diverse community. A comprehensive treatment of functional richness can be found in the paper by Villeger et al. (2008).

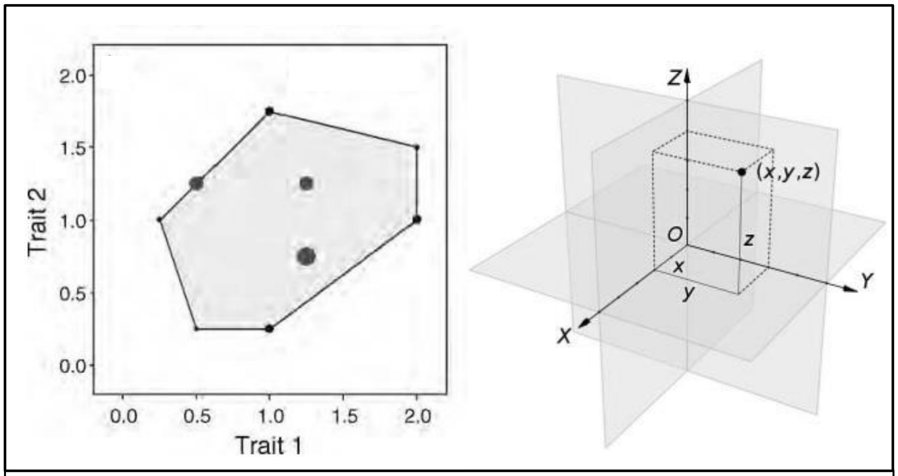

Figure 2. Functional trait space and Functional Richness. Axes represent the range of values for a single functional trait (*n*). Coordinates of a species (*s*) in the *n*-dimensional trait space are the values for each trait (t_1, t_2, t_3,…t_n). Images from Villeger et al. (2008) and www.my-ms.org.

Functional evenness is "the evenness of abundance distribution in a functional trait space" (Villeger et al., 2008). This index measures the regularity of the Euclidean distance (weighted by abundance) between each species and its two most functionally similar species. Functional evenness is measured as a value between 0 and 1 where 1 is a perfectly even distribution of abundance in the trait space. Functional evenness indicates the overall homogeneity of both functional distance between species and abundance.

Relatively uneven separations between species and overly abundant species will lower functional evenness and, by extension, biodiversity. Mathematical calculations for functional evenness and a more comprehensive treatment of the index can be found in the paper by Villeger et al. (2008).

Functional divergence measures “how abundance is distributed within the volume of functional trait space occupied by a species” (Villeger et al., 2008). For this index a “center of gravity” for the functional trait space must be measured. Coordinates for the center of gravity are the sample averages for all functional traits. Functional divergence measures the sample’s divergence (weighted by abundance) from the center of gravity. A higher level of divergence indicates a higher level of diversity. This index is measured between 0 and 1. When a functional divergence value is closer to 0, species of higher abundance have more average functional trait values in relation to the whole sample than the less abundant species; a value closer to 1 indicates that the most abundant species are functional extremities in the sample. Mathematical calculations for functional divergence and a more comprehensive treatment of the index can be found in the paper by Villeger et al. (2008).

Functional dispersion is “the mean distance of individual species to the centroid of all species in the community” (Laliberte and Legendre, 2010). The centroid of the species in the community is weighted by species abundance as well as functional trait values. In a sample where all species are equally abundant, the centroid will be the center point of the functional trait space (the same as the center of gravity); when some species are more abundant than others, the centroid gravitates towards the most abundant species. Functional dispersion is measured starting at zero with no upper limit. A higher functional dispersion value indicates that there is a higher amount of dispersion of species and species abundance in the functional trait space. A high level of dispersion indicates a high level of biodiversity. Mathematical calculations for functional dispersion and a more comprehensive treatment of the index can be found in the paper by (Laliberte and Legendre, 2010).

Together all of these indexes meet the criteria of Mason et al.(2003) and Ricotta (2005). Because of the fact that each index has an inherent shortcoming, none of them should be considered alone as a complete measure of functional diversity. When analyzed in concert, the four indexes can give a complex and comprehensive understanding of the biodiversity in a community.

Analyzing the Monahan Data

In order to compute the above indexes a set of data must have a list of species, abundance for each species, and values for each functional trait by species. The historical data from past Monahan research provides lists of species and abundances for each species (Vickers, 1989; Yates, 1996). However, neither thesis has measurements for any functional traits. Therefore, any functional trait used to analyze the historical data on the Monahan grassland had to be universally applicable to each individual of a plant species regardless of context. “Plant height” is a quantifiable functional trait that can be easily measured in the field; however, it cannot be applied to past data because it is affected by its context. Three functional traits from “A handbook of protocols for standardized and easy measurement of plant functional traits worldwide” (Cornelissen et al., 2003) were quantifiable traits that could be applied to past data: growth form, life form, and spinesence.

Growth form is a trait that describes a species' canopy structure and strategy. Growth form was measured on a scale from 1 to 20 as outlined by Cornelissen et al. (2003); each number on the scale represents a category of growth form. Species with a low growth form are generally short with a low amount of canopy cover and higher growth forms are taller with more canopy cover or have a more elaborate growth strategy (e.g. epiphytes, vines, parasites). Growth form can be measured by using literature to determine a species's growth strategy and applying to correct value. Growth form is informative about plant relations to grazers (Mcintyre and Lavorel, 2001).

Life form is a trait that describes the structure and strategy of a species' meristematic tissue (Cornelissen et al. 2003). Life form had a possible range of values from one to seven as outlined by Cornelissen et al. (2003); each number on the scale represents a category of life form. Categories were based largely on the life forms identified by Raunkiaer (1934). A low life form value means that the plant has a high amount of meristematic tissue distributed far away from the ground; higher life form values mean that there is less perennating tissue and it is lower to the ground or the plant has an elaborate perennating tissue strategy (e.g. aquatic plants). Growth form can be measured by using literature to determine a species's tissue strategy and applying to correct value. Life form is informative about how species of plants interact with their immediate environment (Box, 1996).

Spinesence is a measurement of the character of a species' spine-like structures (Cornelissen et al. 2003). This is not a measurement of the structures currently on a species, but a measure of what the general character of the structures is for the species as a whole. The values for spinesence had a possible range of zero to five as outlined by Cornelissen et al. (2003); each number on the scale represents a degree spinesence harshness. Plants with a lower spinesence value had less spine-like structures (e.g. hairs, prickles, thorns) and less abrasive spine-like structures; plants with higher spinesence value had more spine-like structures and more dangerous spine-like structures. Spinesence can be measured by using literature or field observation to determine a species's spinesence level and applying to correct value. The spinesence trait is informative about species interaction with grazers and similar external threats (Rebollo et al., 2002).

The calculation of each of these traits by species for all historical and present Monahan data completed a set of data that met all necessary parameters to calculate the FD indexes of Villeger et al. (2008) and Laliberte and Legendre (2010). Comparison of these indexes for each sample year of Monahan data will reveal a picture of biodiversity over time on the Monahan. Fluctuation in the values returned by these indexes will illuminate shifts in functional diversity. If the Monahan reclaimed grassland has become a healthier and more stable community, it will be reflected as an increase in functional diversity.

CHAPTER II

MATERIALS AND METHODS

Past Data

One of the main goals of this study was to observe historical trends in species composition and functional diversity. Data from past graduate theses completed at this site was obtained in order to apply FD calculations to their species lists for comparison to data collected for this study. Two past graduate studies sampled vegetation on this site in the same area as this study and each yielded sufficient data for the purposes of comparison to this study (Vickers, 1989; Yates 1996). The data procured from these studies included the lists of species found on the Monahan grassland and their frequencies of appearance in the sample, the parameters required to apply most richness and diversity indices.

Vegetative Sampling

The study area used to collect data for this study as well as the 1989 and 1996 theses was the reclaimed grassland at the Monahan Outdoor Education Center (Figure 3). The boundaries of the sampling area were determined by physical barriers including roads, wetlands, tree lines, and others. A recent aerial view of the Monahan was retrieved from Google Maps (www.google.com/maps) in order to determine where the boundaries should be and GPS coordinates were used to place the sampling area within the physical boundaries.

Figure 3: The Monahan grassland with 2014 sampling plots overlaid.

The sample area consisted of a grid of 45 contiguous 50m by 50m sampling plots (Figure 3). The sampling plot grid was created prior to field work by using GPS coordinates to precisely establish the dimensions of each plot. The plots were then physically located using wooden stakes with orange flagging. Within each plot, five sampling quadrats, 1m by 2m, were randomly placed. Each quadrat was placed at a random distance between 0m and 25m in from the center point of the plot as well as at a random direction between 1° and 360° where straight North is 1° (Figure 4). A PVC sampling square was constructed and used as a physical boundary for each quadrat.

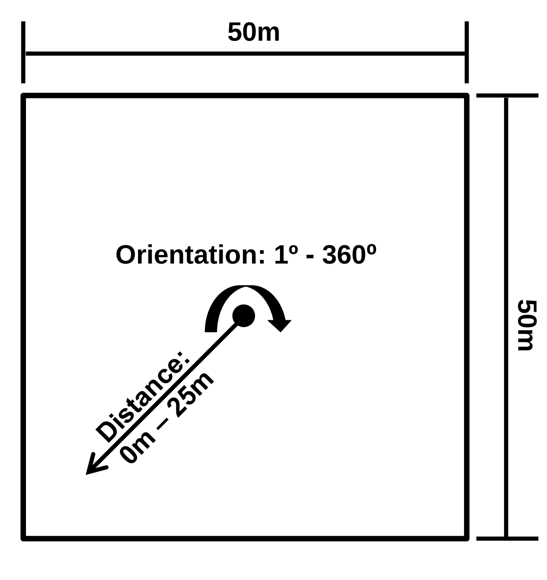

Figure 4. A 50mX50m sampling plot, five quadrats will be placed at randomly assigned orientations and distances from the center point.

Each separate species of plant found in each plot was recorded as well as the frequency of each species in each separate quadrat. Initial identification was conducted in the field and voucher specimens were collected, identified, and deposited at the R.L. McGregor Herbarium, University of Kansas. The data was collected and recorded by quadrat. All quadrats were assigned identifying codes by plot; such as “P1Q1” for plot 1, quadrat 1. Species observed outside of a quadrat were not recorded in the data. Frequency of species in the sample was determined by presence of each species in each quadrat.

Qualitative Analysis Methods

A comparative analysis of the originally seeded species, historically sampled species, and species sampled in this study was conducted. Three factors were looked at in this analysis: the presence/absence of species, their frequencies, and species richness for each sample. It was noted which species were initially seeded and their presence or absence in all following surveys. The frequency and fluctuation of key species was observed and the species richness found in each sample was noted as well.

Statistical Methods – Functional Diversity

The methods used to calculate FD in this study were developed by Villéger et al. (2008) and built upon by Laliberte and Legendre (2010). In order to apply these indexes to the data collected from past studies and this study it was necessary choose three different functional traits that could be determined from historical data where species are identified. The three functional traits used in this study included growth form, life form, and spinesence. These are all traits that can be determined for historical data where species are identified. The values for growth form, life form, and spinesence are determined by "field observation, descriptions, or photos in the literature" (Cornelissen et al. 2003). Each species in this study received a growth form value of 1-20 and a life form value of 1-7 based on the numerical categories assigned to different life and growth forms by Cornelissen et al. (2003). Each species in this study received a spinesence value of 0-5 based on nature of their spines as described by Cornelissen et al. (2003). Values for all three variables were also assigned to all species collected in the past graduate studies.

The program "R" (www.r-project.org) was used to calculate the four different FD indexes. The R package "FD", developed by Laliberte et al. (2014), was used to calculate all indexes. Entry of field data into R required the data to be formatted into two data matrices, a trait matrix and a frequency matrix. The trait matrix included all species found in the survey as rows and their corresponding functional data as columns (Table 2). The frequency matrix included the species as columns and their frequency in the entire sample as a single row (Table 3). With this input the FD package returned the four values used to measure FD in this study. This process was repeated for all past data as well as data collected in this study. After the four FD values were retrieved for past and present data they were compiled and analyzed.

Table 2. Example trait matrix for entry into R. Species is entered as rows and functional trait values as columns. See Appendix B for all trait matrixes used in this study.

	Life Form	Growth Form	Spinesence
Species 1	value	value	value
Species 2	value	value	value
Species 3	value	value	value

Table 3. Example frequency matrix for entry into R. Species is entered as columns and their frequency in the entire sample as the row. See Appendix B for all frequency matrixes used in this study.

	Species 1	Species 2	Species 3
Frequency in sample	Frequency (species 1)	Frequency (species 2)	Frequency (species 3)

CHAPTER III

RESULTS

Species Composition

The original seeding of the Monahan reclaimed grassland was comprised of 21 species (Table 1). Vickers's (1989) graduate thesis was the first reported vegetation survey after the reclamation. Vickers collected two samples in 1987 and 1988. The 1987 sample found 23 species, two more than the original seeding (Table 4). The 1988 sample found 21 species, a decrease of two from 1987. Yates (1996) collected one sample in 1994. Yates identified 35 species, an increase 14 from the 1988 sample (Table 4). The vegetative sampling from this study was conducted in 2014. A total of 29 species were identified, six less than the 1994 sample and eight more than originally seeded (Table 4).

Table 4. Species and frequency collected in vegetative samples by Vickers (1987, 1988), Yates (1994), and Heil (2014). Frequency is derived from presence/absence in sampling units.					
Species	Common Name	Frequency			
		1987	1988	1994	2014
Acalypha virginica	Virginia Mercury	-	-	0.21	-
Achillea millefolium	Common Yarrow	-	-	0.05	-
Amaranthus sp.	-	-	0.01	-	-
Ambrosia artemisiifolia	Ragweed	0.49	0.04	-	0.08
Andropogon gerardii	Big Bluestem	0.01	0.11	0.95	0.15
Aster pilosus	Frost Aster	-	-	0.27	-
Bouteloua curitpendula	Sideoats Grama	0.66	0.73	0.90	0.08
Bouteloua dactyloides	Buffalograss	-	0.03	0.08	0.06
Carex sp.	-	-	-	0.14	-
Cirsium altissimum	Tall Thistle	-	-	-	0.004
Conyza canadensis	Horseweed	0.04	-	0.05	0.05
Cornus amomum	Swamp Dogwood	-	-	-	0.04
Cornus dromundii	Roughleaf Dogwood	-	-	0.08	0.04
Dalea candida	White Prairie Clover	0.12	-	-	-
Dalea purpurea	Purple Prairie Clover	0.04	0.02	0.18	-
Desmanthus illinoensis	Illinois Bundleflower	-	0.01	0.11	0.01
Dicanthlium sp.	-	-	-	0.12	-
Echinochloa crus-galli	Barnyardgrass	0.01	0.01	-	-
Elaeagnus umbellata	Autumn Olive	0.01	-	-	-
Elymus sp.	-	0.02	-	-	-
Erigeron strigosus	Prairie Fleabane	-	-	0.83	-
Eupatorium rugosum	White Snakeroot	-	-	0.08	-
Eupatorium altissimum	Late Eupatorium	-	-	-	0.14
Euthamia gymnospermoides	Grass-leaved Goldenrod	-	-	0.07	-
Festuca pratensis	Meadow Fescue	-	-	0.10	-
Festuca sp.	-	0.01	0.04	-	-
Gaura biennis	Biennial Gaura	-	-	0.14	-
Geum vernum	Spring Avens	-	-	0.18	-
Helianthus annuus	Common Sunflower	0.05	0.01	-	-
Helianthus maximiliani	Maximilian Sunflower	-	0.02	0.32	0.04
Iva annua	Marsh Elder	0.02	0.01	-	-
Melilotus officinalis	Yellow Sweet Clover	0.92	0.01	0.12	0.77
Oenothera villosa	Hairy Evening Primrose	-	-	-	0.05
Oxalis dillenii	Slender Yellow Woodsorrel	-	-	0.09	-

Table 4 (cont.). Species and frequency collected in vegetative samples by Vickers (1987, 1988), Yates (1994), and Heil (2014). Frequency is derived from presence/absence in sampling units.					
Species	Common Name	Frequency			
		1987	1988	1994	2014
Panicum capillare	Witchgrass	-	-	0.09	-
Panicum virgatum	Switchgrass	0.52	0.56	1.00	0.74
Pascopyrum smithii	Western Wheatgrass	0.10	0.07	0.69	0.01
Passiflora incarnata L.	May-pop	-	-	-	0.004
Physalis heterophylla	Clammy Ground Cherry	-	-	-	0.004
Physalis longifolia	Longleaf Groundcherry	-	-	0.08	-
Physalis sp.	-	0.01	-	-	-
Poa pratensis	Kentucky Bluegrass	-	-	0.26	0.01
Populus deltoides	Cottonwood	0.01	-	0.05	0.08
Pycnanthemum tenuifolium	Slender Mountain Mint	-	-	0.09	-
Ratibida pinnata	Yellow Coneflower	-	-	0.08	-
Rhus copallina	Winged Sumac	-	-	-	0.04
Rhus glabra	Smooth Sumac	-	-	-	0.04
Rubus Flagellaris	Dewberry	-	-	-	0.02
Rubus occidentalis	Black Raspberry	-	-	-	0.01
Rubus ostryifolius	Highbush Blackberry	-	-	-	0.01
Schyzachyrium scoparium	Little Bluestem	0.05	0.10	0.76	0.06
Setaria parviflora	Knotroot Bristlegrass	0.01	0.01	-	-
Solanum carolinense	Carolina Horsenettle	-	0.01	-	-
Solanum dimidiatum	Western Horsenettle	-	-	-	0.01
Solidago canadensis	Canada Goldenrod	-	-	0.97	-
Solidago sp.	Goldenrod sp.	0.83	0.05	-	0.72
Sorghastrum nutans	Indiangrass	-	-	0.74	0.37
Sphenopholis obtusata	Prairie Wedgescale	-	-	0.21	-
Sporobolus asper	Dropseed	-	-	0.21	-
Symphoricarpos orbiculatus	Coralberry	0.05	0.06	-	0.04
Symphyotrichum subulatum	Saltmarsh Aster	0.36	0.01	-	-
Tripsacum dactyloides	Eastern Gamagrass	-	-	0.06	-
Xanthium sp.	-	0.01	-	-	-

Of the originally seeded species, seven were grass species, three were forbs, and eleven were woody (Table 1). Ten of the original species survived on the grassland and were sampled in the 1987-88 samples (Table 4). One woody species survived to the 1987 vegetative sample (*Elaeagnus umbellata*) and one woody species invaded prior to the 1987 sample (*Populus deltoides*). While both species were found in the 1987 sample, they were absent in the 1988 sample. Fifteen species of forbs were found in the 1987-88 samples, an increase of 12 from the original seeding; two of the three originally seeded forbs were found (*Dalea purpurea*, *Helianthus maximiliani*). All grass species originally seeded were found in the 1987-88 samples as well as four new grass species.

The 1996 vegetative sample found 35 different species on the Monahan (Table 4). *Populus deltoides* was the only woody species found in the 1994 sample. All woody species that were originally seeded were absent (Table 1). The number of forb species found in 1996 increased to 21, six more than the 1988 sample (Table 4). The species *Ratibida pinnata* had been originally seeded, was absent from the 1987-88 samples, and showed up again in the 1996 sample. Thirteen grass species were identified in the 1996 sample, an increase of two from the 1988 sample.

This 2014 study identified 29 different species on the Monahan (Table 4). The number of woody species has increased from one species in 1994 to eight, three less than originally seeded (Table 1, Table 4). None of the originally seeded woody species were found in this study. The number of forb species has dropped to 14; the number of grass species has dropped to seven.

Species frequency fluctuated between the different studies. In 1987 three of the five most frequently sampled species were forbs; the other two were grass species (Table

4). The most frequently found species was *Melilotus officinalis*, a forb; *Melilotus* was found in 92% of the 1987 quadrats. In 1988 *Bouteloua curtipendula* was the most frequently sampled species (0.73), there were no forb species among the top five most frequent species, and the frequencies overall were lower (Table 4). The 1996 sample showed a mix of grass and forbs making up the most frequent species (Table 4); the most frequent species, *Panicum virgatum*, was present 100% of the time. In 2014 two of the top five species were forbs and three were grasses (Table 4); the most frequently found species was *Melilotus officinalis* (.77).

Functional Trait Values

Functional trait values fluctuated from year to year based on the different species found in each sample. The first trait measured was growth form. Growth form was measured on a scale from 1 to 20 as outlined by Cornelissen et al. (2003). The highest mean growth form for a whole sample was recorded in 2014 at 6.31 (Figure 5). The second highest mean growth form value was from the 1987 sample (5.26) followed by 1988 (5.25) and 1994 (5.16). The highest recorded growth form value (15) was from the 2014 sample; all other years had maximum growth form values of six. Every sample had a minimum growth form value of three (semi-basal plants). The 1987, 1988, and 1994 samples all had a 50% of species valued between four and six; the 2014 sample was mostly spread between four and eight.

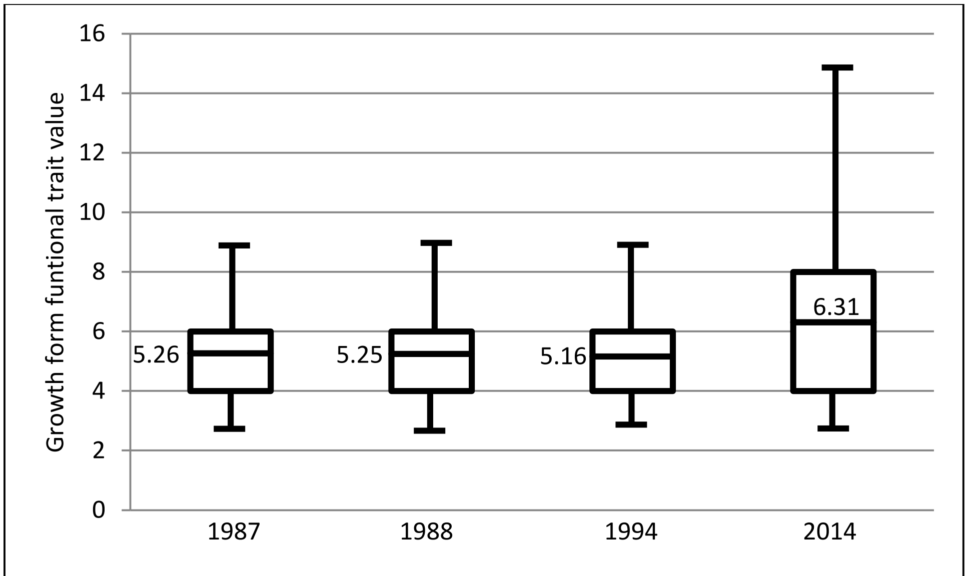

Figure 5. Sample growth form values by year. (Vickers 1989, Yates1996)

The second functional trait measured was life form. Life form had a possible range of values from one to seven as defined by Cornelissen et al. (2003). As observed in growth form values, life form values also shifted from year to year (Figure 6). The 1987, 1988, and 1994 samples all had average life form values within 0.4 of each other (3.79, 3.75, and 3.46 respectively). The 2014 sample had the lowest average life form value at 2.97. The majority of species sampled in 1987, 1988, and 1994 were grouped between 3 and 5, and the 2014 sample showed a spread from 1.5 to 5. All samples had a maximum life form value of five (represented by, for example, *Ambrosia artemisiifolia*) and minimum of one (represented by, for example, *Elaeagnus umbellata*).

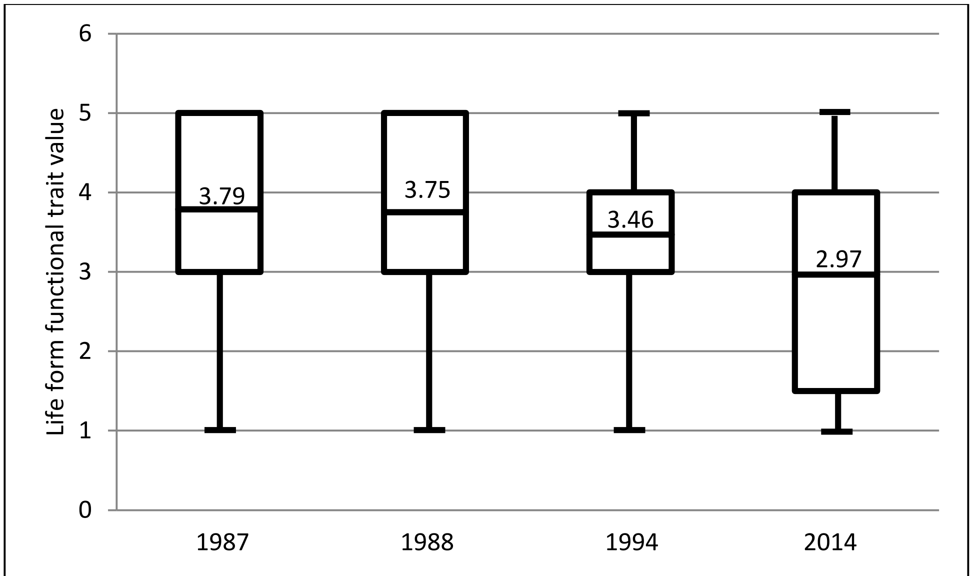

Figure 6. Sample life form values by year. (Vickers 1989, Yates1996)

The third functional trait measured was spinesence. The values for spinesence had a possible range of zero to five (Cornelissen et al. 2003). The highest mean trait value for spinesence was in the 2014 sample (0.72); the 1987 sample had the second highest mean (0.58), 1988 (0.40) and 1994 (0.34) followed (Figure 7). All samples had a majority of species valued at either zero or one and all samples had a minimum value of zero (minimal spinesence). 1987 had the highest maximum spinesence value at five (represented by *Elaeagnus umbellata*). 1994 and 2014 each had a maximum spinesence value of three and 1988 (2).

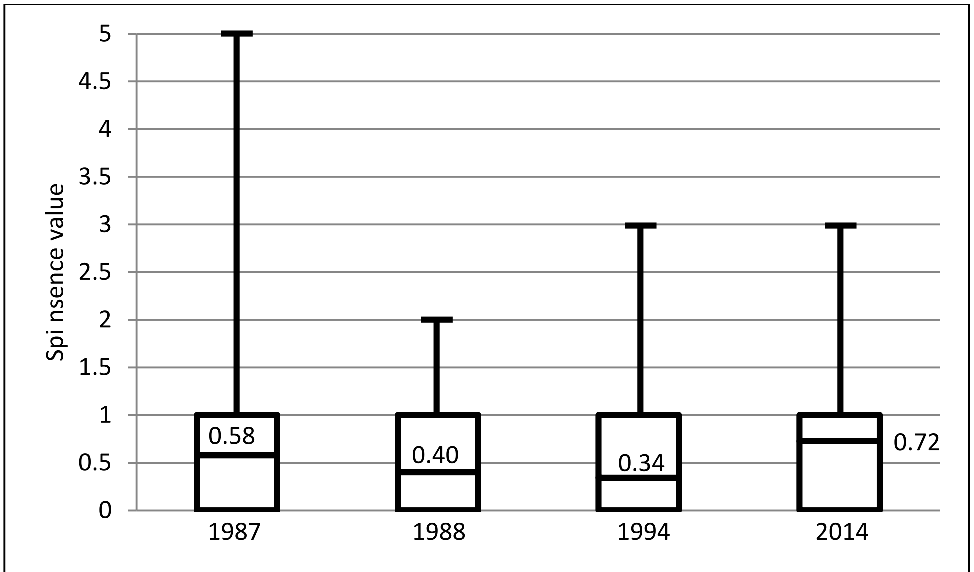

Figure 7. Sample spinesence values by year. (Vickers 1989, Yates1996)

Functional Richness, Evenness, Divergence, and Dispersion

The three functional traits were concatenated for each species and used along with frequency to calculate the FD indexes for each of the four surveys (Table 5). Not all species have a unique combination of functional trait values and every sample showed a higher species richness than functionally unique combinations. The 1994 sample was the sample with the highest number of functionally unique trait combinations (25). The 2014 sample had the second most unique combinations (18), followed by 1987 (17), and 1988 (16).

Table 5. Functional diversity values for all samples. (Vickers 1989, Yates 1996)

	1987	1988	1994	2014
Number of unique functional trait combinations	17	16	25	18
Functional Richness	8.479	9.961	8.828	12.171
Functional Evenness	0.176	0.456	0.305	0.270
Functional Divergence	0.679	0.940	0.751	0.645
Functional Dispersion	1.089	0.630	1.241	0.952

Functional richness is the volume of the Functional Trait space occupied by each sample (Villeger et al., 2008). A high functional richness indicates that the community hosts a relatively large range of functional traits. The 2014 sample had a functional richness of 12.171, the highest value of any sample year (Table 5). The 1988 sample had the second highest functional richness (9.961), which was followed by 1994 (8.479). The least functionally rich sample year was 1987 (8.479).

Functional evenness is "the evenness of abundance distribution in a functional trait space" (Villeger et al., 2008). Functional evenness is measured as a value between 0 and 1 where 1 is a perfectly even distribution of abundance in the trait space. The 1988 sample had an evenness value of 0.456 and was the most functionally even sample year (Table 5). The 1994 sample had the second highest evenness value (0.305) which was followed by 2014 (0.270). The 1987 sample had an evenness value of 0.176 and was the least functionally even year.

Functional divergence measures "how abundance is distributed within the volume of functional trait space occupied by a species" (Villeger et al., 2008). This index is measured between 0 and 1. When a functional divergence value is closer to 0, species of higher abundance have more average functional trait values in relation to the whole sample than the less abundant species; a value closer to 1 indicates that the most abundant species are functional extremities in the sample. The 1988 sample had a functional divergence value of 0.940; this was the most functionally divergent sample year (Table 5). The next most divergent year was 1994 (.751) which was followed by 1987 (0.679). The least functionally divergent sample year was 2014 (0.645).

Functional dispersion is “the mean distance of individual species to the centroid of all species in the community” (Laliberte and Legendre, 2010). A higher functional dispersion value indicates that there is a higher amount of dispersion of species and species abundance in the functional trait space. The 1994 sample had a dispersion value of 1.241; it was the most functionally dispersed sample year (Table 5). 1987 had the second highest functional dispersion (1.089) and 2014 followed (0.952). The 1988 sample had the least functional dispersion of any sample (0.630).

CHAPTER 1V

DISCUSSION

1987 – Jeff L. Vickers

The 1987 sampling conducted by Jeff L. Vickers was the initial vegetative survey on the Monahan following the reclamation process (Vickers, 1989). Vickers found a higher number of species present on the Monahan than had originally been seeded (Table 1, Table 4); however only 8 of the 23 species in the 1987 sample were species that had been included in the original seeding. At least 15 species had invaded the grassland in the three years since reclamation.

The shifting trends of functional traits can be traced in these initial observations. Only one woody species (*Elaeagnus umbellata*) out of the seven that were originally planted was found in the 1987 sample. Other species surviving from the initial planting included two forb species and four grass species (Table 4). The 1987 sample also found that one woody species (*Populus deltoides*), 12 forb species, and four grass species had been introduced to the grassland since reclamation.

A change in species composition can lead to a shift in functional trait composition. This is reflected in the functional trait value makeup of the 1987 sample. Most of the species in this sample had a growth form value of 4, 5, or 6 with a mean of 5.26 (Figure 5); this range of growth forms encompasses tall leafy plants, cushions, and tussocks (Cornelissen et al. 2003). Only the two woody species had growth forms over 6. All species in the sample, except the two woody species had life form values of 3, 4, or 5; these values encompass annual plants and perennials that reduce to vegetative buds or root systems in winter (Cornelissen et al. 2003). Only one plant (*Elaeagnus Umbellata*) had greater spinesence value than 1. In 1987 the overall functional community was composed mostly of erect herbaceous plants that had little physical protection against herbivory (spines) and reduced to nodes or roots during the winter.

The 1987 sample had the lowest functional richness of all the sample years (Table 5). Having a lower functional richness indicates that this sample had comparatively less biodiversity than the other sample years because it occupies a lower volume of functional trait space (Villeger et al. 2008, Figure 8). 1987 also had the second to least number of unique functional trait value combinations (Table 5). This affects the functional richness of a sample, which will decrease when there are species present with identical sets of functional trait values because they will also have identical coordinates in the functional trait space. Those species with the most potential to expand the functional richness of a sample are the species with extreme functional trait values compared to the rest of the sample. An example from the 1987 sample of a species with functionally extreme trait values is *Elaeagnus umbellata* which had coordinates of (8,1,5); the spinesence value of 5 indicates that this species has many dangerous thorns, which was uncommon in the 1987 sample. Therefore, the scarcity of extreme traits caused a relatively low level of functional richness in 1987.

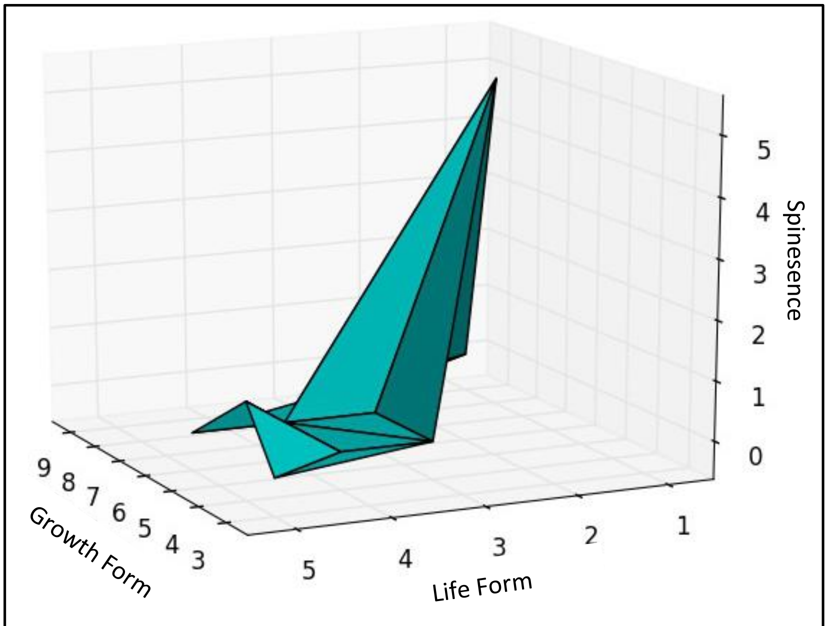

Figure 8. Functional trait space of the 1987 sample (Vickers 1989). Functional richness is measured as the volume of the convex hull surrounding the trait space.

The 1987 sample also had the lowest functional evenness (Table 5). The most abundant species in the 1987 sample were more functionally closer than those of other sample years. This is an indicator of lower community biodiversity. If the most abundant species all have similar functional trait values then the community is probably comparatively functionally homogenous. In the 1987 sample the functionally extreme woody species were both only found in 1% of the quadrats. In order for this sample to be more functionally even these functionally extreme species would need to have higher abundance, or the whole sample would need to be equally abundant and be of equal Euclidean distance to each other in the functional trait space.

The 1987 sample had the second lowest functional divergence value after 2014 (Table 5). When a sample has a lower functional divergence it is an indication that the sample also has less biodiversity because the most abundant species will be close to the center of functional trait space. The 1987 sample had a lower functional divergence than the 1988 and 1994 samples and was higher than the 2014 sample. The coordinates for the center of gravity can be found by taking the average of each functional trait value for the sample; the center of gravity for the 1987 sample was (5.3, 3.8, 0.58). In order to increase functional divergence the 1987 sample would need more abundant species that had combinations of traits farther from the mean.

The 1987 sample had the second highest functional dispersion (Table 5). A lower functional dispersion in a sample indicates that there is less dispersion of species and abundance in the functional trait space. A higher amount of dispersion indicates a higher level of biodiversity in the sample. The 1987 sample had a higher amount of dispersion of species and species abundance than the 1988 and 2014 sample and it was lower than the 1994 sample.

The 1987 sample showed a shift toward a mix of forbs and grass. Woody species were all but absent in the 1987 sample. The remaining woody species represented functional extremes and were among the least abundant species in the sample. The 1987 sample had the lowest value in two functional diversity indexes (richness and evenness) compared to all other samples; it did not have the highest value in any of the function diversity indexes.

1988 – Jeff L. Vickers

The 1988 sample was the second sample conducted by Vickers (1989). Vickers repeated the 1987 methodology in his second sampling. 21 species were recorded in the 1988 sample, two less than the recorded amount in 1987 (Table 4). The number of originally seeded species recorded in 1988 increased to nine, one more than 1987 (Table

1). Two originally seeded species, *Bouteloua dactyloides* and *Helianthus maximiliani*, reappeared in the sample and one original species *Elaeagnus umbellata* disappeared.

In between these two sample years, part of the grassland was burned and part of the grassland was harvested for hay (Vickers 1989). Vickers postulated that these two events caused grass species to become more dominant than other types of species on the grassland. A comparison of the species compositions from the 1987 and 1988 sample reveals a possible shift in functional diversity. One noticeable difference between the samples is the complete lack of woody species in the 1988 sample; both woody species found in 1987 did not reappear in 1988 (Table 4). It is possible that woody species still existed on the grassland, but they would have been rare enough to avoid detection in the 1988 sample.

A shift towards the dominance of grass species in the 1988 sample is also evidenced by the frequencies of the species in the sample. The five most frequently appearing species in the 1988 sample are grasses; this is a contrast to the 1987 sample where the two most frequent species were forbs (Table 4). In the 1987 sample the most frequent species, *Melilotus officinalis*, had been found in 92% of the quadrats and was found in only 1% of the 1988 sample. Overall only six species, all grasses, saw an increase in frequency from 1987 to 1988.

If the ratio of individual grass species to non-grass species present in the sample had shifted, it would appear in a cursory examination of the raw functional trait data. Most grasses in these surveys occupied very similar functional trait sets. The average life and growth forms in the community would gravitate towards 3 and 6. However, any change in the frequencies of individual species is not reflected in the raw functional trait data. The values for the growth form trait showed the same maximum and minimum values in 1987 and 1988; both years showed that 50% of species were grouped between the values 4 and 6 (Figure 5). The mean growth form value for 1988 was 5.25, a decrease of .1 from 1987. The life form trait showed a similar amount of change. The 1987 and 1988 samples had the same maximum and minimum values for 1987 and 1988; in both years the bulk of species were grouped between the values 3 and 5 (Figure 6). Their mean life form value for 1988 was 3.75, a decrease of .3 from 1987. The third trait, spinesence, showed more change from 1987 to 1988 than the other two traits. The maximum spinesence value in 1988 was 2, a difference from the 1987 maximum of 5 (Figure 7). In both years the bulk of spinesence values fell between 0 and 1. The mean spinesence value was 0.40 in 1988, a decrease of 0.18 from 1987.

Little change was seen between 1987 and 1988 from the raw functional trait data. Any shift in functional diversity between the two samples is more likely to be reflected in the functional diversity indexes that are based on frequency of individual species in the sample. The functional diversity indexes used in this study are affected by species frequency to varying degrees (Villeger et al. 2008, Laliberte and Legendre, 2010). Species richness does not take frequency into account, so it would not be affected by a shift in frequencies. The other three indexes all are calculated using frequency and will be affected by shifting frequencies.

The functional richness value for the 1988 sample confirms that this index will not respond to a shift in frequency of individual species. The 1988 sample had the second highest functional richness of any sample year (Table 5). It showed an increase of about 1.5 from the 1987 sample. This indicates that the functional trait space on the Monahan was larger in 1988 than it was in 1987 despite actually having a lower number of unique functional trait combinations (Figure 9). A larger functional trait space indicates that overall biodiversity increased between the two sample years. However, the change in species frequency observed in the raw data suggests that there are potential changes in biodiversity on the Monahan between 1987 and 1988 that cannot be observed by using this index.

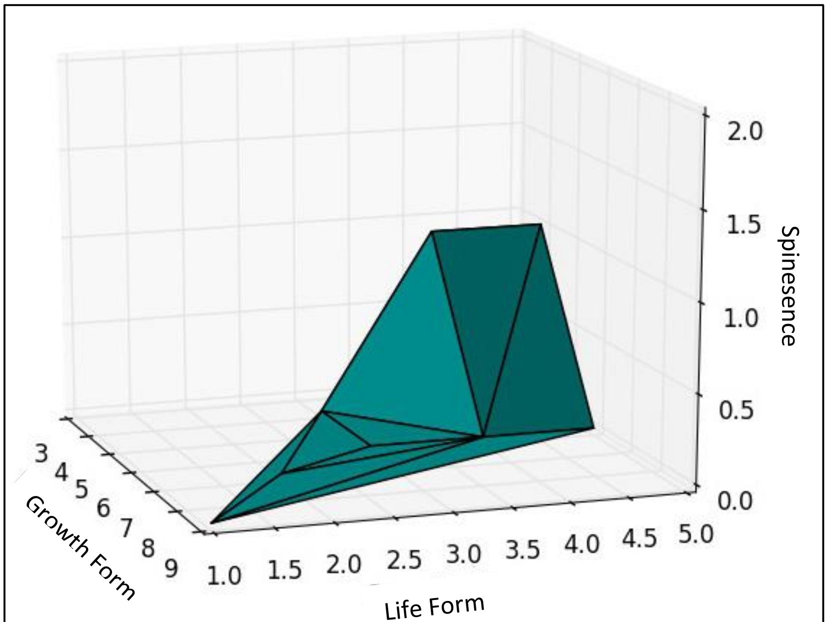

Figure 9. Functional trait space of the 1988 sample. (Vickers 1989)

The 1988 sample had the highest functional evenness of any sample year (Table 5). There was an increase of 0.28 from the 1987 to the 1988 sample. This indicates that biodiversity increased between the two sample years and that species abundance was distributed more evenly in functional trait space. Raw data shows that while grasses became the most dominant types of species, almost all species decreased in abundance and only two species in the whole sample were found more than 11% of the quadrats (Table 4). This observation is confirmed by the functional evenness index. There is a higher level of evenness in 1988 because almost every species has a relatively lower abundance. Grass species are the most abundant species in the sample, but there is a smaller frequency difference between all species than there was in 1987.

The 1988 sample also had the highest functional divergence of any sample year (Table 5). There was an increase of 0.260 from 1987 to 1988, indicating a higher level of biodiversity due to the more abundant species having a higher divergence from the center of the functional trait space. The increase of functional divergence in 1988 can be found in the raw data (Table 4). The frequency of most species in the 1988 sample was relatively low compared to the 1987 sample. The only two species that had frequencies over 11% (*Bouteloua curtipendula*, *Panicum virgatum*) were functionally identical based on the three traits measured (Appendix A). The abundance was unevenly distributed and the lack of highly abundant species allowed the two most abundant species to increase the functional divergence of the entire sample.

In 1988, the only functional diversity metric that suggested relatively low biodiversity compared to the other sample years was functional dispersion (Table 4). There was a decrease of 0.459 in functional dispersion from 1987 to 1988. This indicates that biodiversity decreased due to a lower amount of dispersion of abundance in the functional trait space. The two most abundant species in the 1988 sample (*Bouteloua curtipendula*, *Panicum virgatum*) were functionally identical causing the centroid to gravitate towards a single point in the functional trait space (Appendix A). Functional dispersion was relatively low because the centroid was close to these two species causing the average Euclidean distance of the sample to the centroid to be lower. The functional dispersion index shows a decrease in biodiversity from 1987 to 1988 due to the overwhelming abundance of two species.

Vickers (1989) observed from his raw data that in 1988 there was shift in the Monahan community towards grass species and a shift away from forb and woody species. Woody species were completely absent from the 1988 sample. Functional diversity indexes indicated that the biodiversity of the 1988 sample was higher than 1987 in that it occupied a larger functional trait space and the frequency of most species was relatively close. However, low levels of abundance for most species in the sample allowed for a few species to dominate the community. Functional divergence and functional dispersion revealed that the two most abundant species in the sample caused a relatively high level of divergence and a relatively low level of dispersion due to their functional similarity. The 1988 sample occupied a relatively diverse functional trait space, but most species had low abundance and the community was dominated by two species.

1994 – Karen Frances Yates

The second graduate study to sample vegetation on the Monahan was conducted in 1994 by Karen Frances Yates (1996). Yates reported 35 different species in her sample, an increase of 14 from the 1988 sample (Table 4). Ten of the species reported in the 1994 sample had been present in the original seeding (Table 1). This was the largest amount of original species observed in any sample year. One forb species, *Ratibida pinnata*, which had been originally seeded and absent from either previous sample, reappeared.

By the year 1994, six years had elapsed since the last vegetative survey; this was the longest time since reclamation that the Monahan had gone without being surveyed.

The raw data collected in the 1994 suggests that changes in functional diversity have occurred since the 1988 sample. One change that can be observed from the raw data is an increase in species richness. In the 1994 sample Yates reported 35 different species, an increase of 14 from the 1988 sample (Table 4). Grass species and woody species showed relatively slight increases in richness since the 1988 sample; forb species saw the greatest increase in species richness, ten more than reported in the 1988 sample. The ratio of forb species to grass species indicates a functional shift away from the dominance of grass species seen in the 1988 sample.

Functional diversity is measured considering both species abundance and species richness. Species richness alone gives a superficial understanding of any possible shifts in functional diversity. The 1994 sample showed an overall increase in abundance since the 1988 sample (Table 4). The increase in abundance for many species could result in a shift in functional evenness, divergence, or dispersion.

The raw functional trait data for the 1994 sample does little to illuminate any possible change in functional diversity. The growth form values had an identical range and quartiles as both the 1987 and 1988 samples (Figure 5). The average growth form value for the 1994 sample decreased by 0.10 from the 1988 sample. The 1994 life form data also showed an identical range and a slight trend downwards in average from both previous samples (Figure 6). The 1994 raw spinesence data was also relatively similar to the 1988 data; the only noticeable changed being an increase in the maximum value to three (Figure 7). Overall there was little noticeable change in the raw functional trait values. Any change in functional diversity was most likely derived from the increased species richness and the frequency of individual species in the sample.

The functional richness of the 1994 sample was the second lowest of any sample year (Table 5). There was a decrease in functional richness of 1.14 from the 1988 sample; indicating a lower biodiversity and a smaller functional trait space (Figure 10). The increase in species richness from 1988 to 1994 did not result in an increase in functional richness, nor did the increase in number of unique functional trait combinations. The decrease in functional trait space coupled with the increase in species richness indicates that there are a greater number of species competing within a smaller range of functional niches.

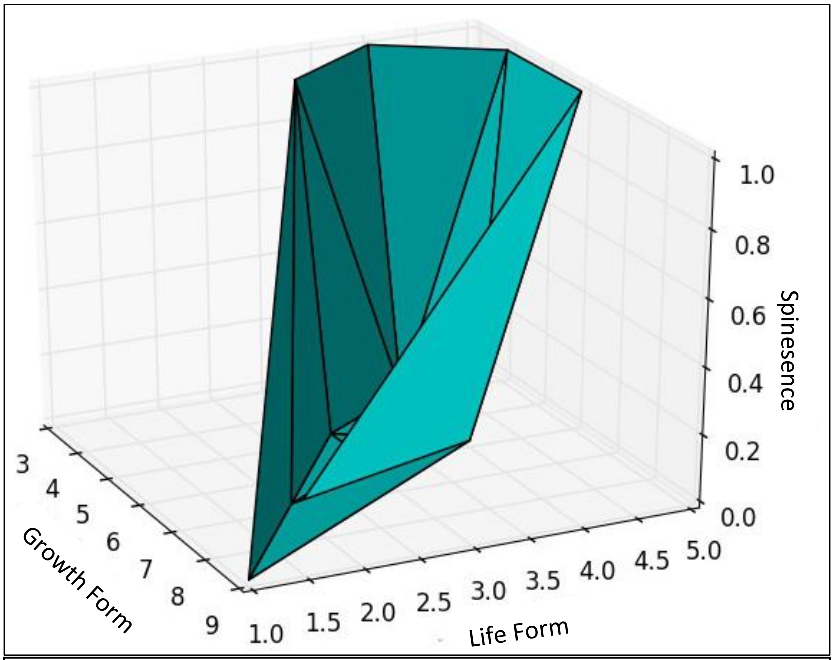

Figure 10. Functional trait space of the 1994 sample (Vickers 1996).

The functional evenness of the 1994 was a decrease from the 1988 sample (Table 5). A higher variance in individual species frequency most likely accounts for the decrease in functional evenness from 1988 to 1994. The 1988 sample was more functionally even than the 1994 sample due to the relatively narrow range of frequencies seen in the bulk of its species. The 1994 sample had higher overall species frequencies than the 1988 sample (Table 4). The level of functional evenness seen in 1994 was relatively high among the sample years and the decrease from 1988 is largely due to an increase in species frequencies.

The functional divergence value for 1994 showed a decrease from the 1988 sample (Table 5). The 1988 sample was shown to have a relatively high functional divergence due to the extreme dominance of two functionally identical species. The frequency of individual species was more widely distributed between different types of species in the 1994 sample as compared to 1988. In the 1988 sample the top five most frequent species were all grasses and only the top two were found in more than 11% of the sample (Table 4). In the 1994 sample the five most frequent species were a mix of grass and forb species and all of the five most frequent species were present over 80% of the time (Table 4). The center of gravity for the 1994 functional trait space was (5.14,3.47,0.34) (Appendix A). The two most frequent species in the 1994 sample, *Panicum virgatum* and *Solidago canadensis*, had coordinates in the functional trait space of (6,3,0) and (4,3,1) respectively. While both species share a common life form, they are on opposite sides of the center of gravity in both growth form and spinesence. The relatively high frequencies of these two species on opposite sides of the center of gravity results in a relatively high functional divergence.

The 1994 sample had the highest functional dispersion value of any sample year (Table 5); there was an almost twofold increase in functional dispersion from the 1988 sample. The high level of functional dispersion indicates that the species reported in the 1994 sample had a relatively even frequency distribution and were dispersed relatively widely throughout the functional trait space. The 1988 sample's lower level of dispersion resulted from the dominance of two functionally identical species. The 1994 sample was shown to have relatively high diversity of functional trait values found in the sample's most abundant species in comparison to the 1988 sample.

Out of every sample year, the 1994 sample had the highest species richness and the highest richness of unique functional trait value combinations. Species composition indicated that the dominance of grasses in 1988 had equalized more between grasses and forbs; however, woody species were still largely absent. Little change was seen in the raw functional trait composition. Despite the high levels of species abundance and trait combinations, the 1994 sample showed a decrease from 1988 in functional richness, evenness, and divergence. However, the 1994 sample showed the highest level of functional dispersion in any sample year.

2014 – Jacob A. Heil

The vegetative survey for this graduate thesis was conducted in the summer of 2014. The 2014 sample was taken 20 years after the previous sample; this was the longest time that the Monahan grassland had ever gone without being sampled. In the years since the 1994 survey, habitat disruption has occurred in the form of controlled burns, haying, and habitat construction among other things. It is likely that a shift in functional diversity occurred as a result of selective pressure from these disruptions. The measurement of functional diversity provides an understanding of the Monahan grassland community during the 2014 sample and comparison to the 1994 sample will reveal any shifts in functional trends between the two samples; however, it is most likely impossible to adequately account for all events on the Monahan grassland that would have caused functional shifts between 1994 and 2014.

The raw species composition data reveals a lower level of species richness in the 2014 sample compared to 1994. (Table 4); twenty-nine species were recorded in the 2014 sample, a decrease of nine from the 1994 sample. Overall there were six less grass species and seven less forb species. Eight species from the original seeding remained (Table 1). Perhaps the most notable change can be seen in the number of woody species in the 2014 sample. There were eight woody species reported in the sample which is six more than any other sample year (Table 4). The original seeding contained 11 woody species, none of those species were included in the eight reported in 2014 (Table 1).

The shift in functional diversity indicated by a relatively high number of woody species may be misleading because the frequencies of all woody species in the sample were relatively low (Table 4). Grasses and forbs remained among the most frequently observed species; *Melilotus officinalis*, a forb, was the most frequently found species in the entire sample. In the measurement of functional diversity, the high number of woody species will yield a larger functional trait space for the sample, but may cause a drop in functional evenness due to the low frequency of woody plants.

The raw functional trait values some interesting differences that separate the 2014 sample from past samples. The 2014 sample had a maximum growth form value of 15 due to the presence of *Passiflora incarnata L.* (May-Pop) (Figure 5, Appendix A). Past sample years all had maximum growth form values of nine. The 2014 sample had the highest average growth form value of any sample year. The life form values for the 2014 sample also deviated somewhat from past samples (Figure 6); the average life form value in the 2014 sample was lower than any other year. The spinesence values found in the 2014 were relatively typical compared to past years (Figure 7). The changes in growth form and life form are largely due to a few species, such as *Passiflora incarnata L.*, which have low frequencies.

The 2014 sample had the highest level of species richness found in any of the sample years (Table 5), resulting in the highest volume of functional trait space (Figure 11). In this index all species have equal weight in determining the end value. Species that have extreme functional trait values and low frequencies have the ability to increase the functional richness of a sample in equal proportion to species that are highly frequent and relatively functionally normal. This can be seen in the 2014 sample by examining the species *Passiflora incarnata L.*, a species with a relatively extreme growth form value and a low frequency. For this reason, functional richness is useful as a measurement for understanding the range of functional values that can be supported in a community, but not what functional values are the most successful and widespread. The high functional richness of the 2014 sample shows that the range of functional niches supported on the Monahan has increased from earlier samples.

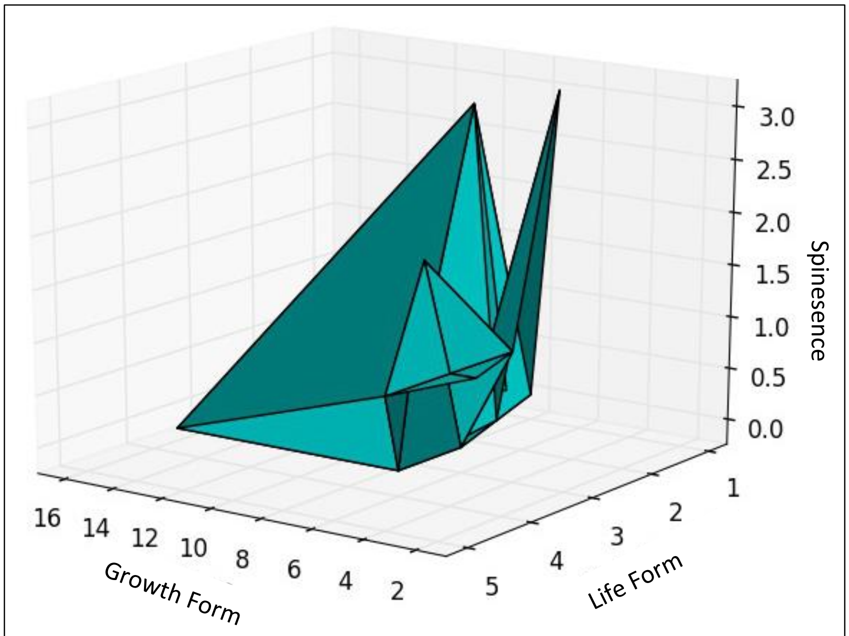

Figure 11. The functional trait space of the 2014 sample.

The 2014 sample had the second lowest functional evenness of any sample year (Table 5). The only sample with a lower functional evenness was the 1987 sample. This indicates a lack of biodiversity due to the relatively poor distribution of abundance among species in the functional trait space. The functionally extreme species found in the 2014 sample were relatively infrequent compared to species with more average functional trait values. The same species that expanded the 2014 functional space caused the sample to be relatively functionally uneven.

The 2014 sample had the lowest functional divergence of any sample year (Table 5). The 2014 sample's most frequent species were closer to the center of gravity than its most functionally extreme species, resulting in a low divergence. A low functional divergence indicates a low biodiversity because it shows that the sample is mostly made up of functionally average species; a more highly diverse community is expected to have a greater divergence from the functional trait averages and higher abundance among more functionally extreme species.

The 2014 sample had the second lowest functional dispersion of any sample year (Table 5). The only year to have a lower functional dispersion was 1988. The relatively low level of dispersion in 2014 indicates that the most abundant species were close to each other in functional trait space. A low functional dispersion indicates a low level of biodiversity because it shows that the abundance of the 2014 sample was highest within a small range of functional values and functionally extreme species were relatively infrequent. Highly diverse communities would be expected to have abundance dispersed more widely among different functional niches.

The 2014 sample revealed a community that had decreased in species richness since it had last been sampled (Table 4). The species composition of the 2014 sample indicated that there was a shift towards a larger presence of woody species than had been found in previous samples. This expansion of woody species richness resulted in a higher level of functional richness than any other sample (Table 5). However, the functionally extreme species that expanded the 2014 functional trait space were a minority in the community. The most frequent species in the 2014 sample were functionally average and caused the evenness, divergence, and dispersion of the sample to be relatively low compared to other sample years. The factors that caused an expansion in functional richness did not yield an increase in the other aspects of functional diversity.

Functional Diversity

Functional richness measures the biodiversity of a community by quantifying its observed breadth of traits. As a measure of biodiversity it is incomplete because it does not account for the important factor of abundance of species within the community. This is illustrated by the 2014 sample (Figure 12). The 2014 sample had the highest functional richness of all the sample years considered in this study, but was among the lowest two samples in all other indexes. The breadth of the 2014 sample was larger than all other years, but the functionally extreme species had relatively low abundances and had little effect on the other FD indexes. It is important to note the breadth of the functional trait space because all other measurements exist within it. The functional trait space exhibits the observed potential range of functional trait values for the sample and all other indexes measure how species interact within that range. The expansion of functional richness in 2014 indicates that the sample area is populated by a more functionally diverse set of species despite the fact that it is increasingly dominated by a smaller range of species.

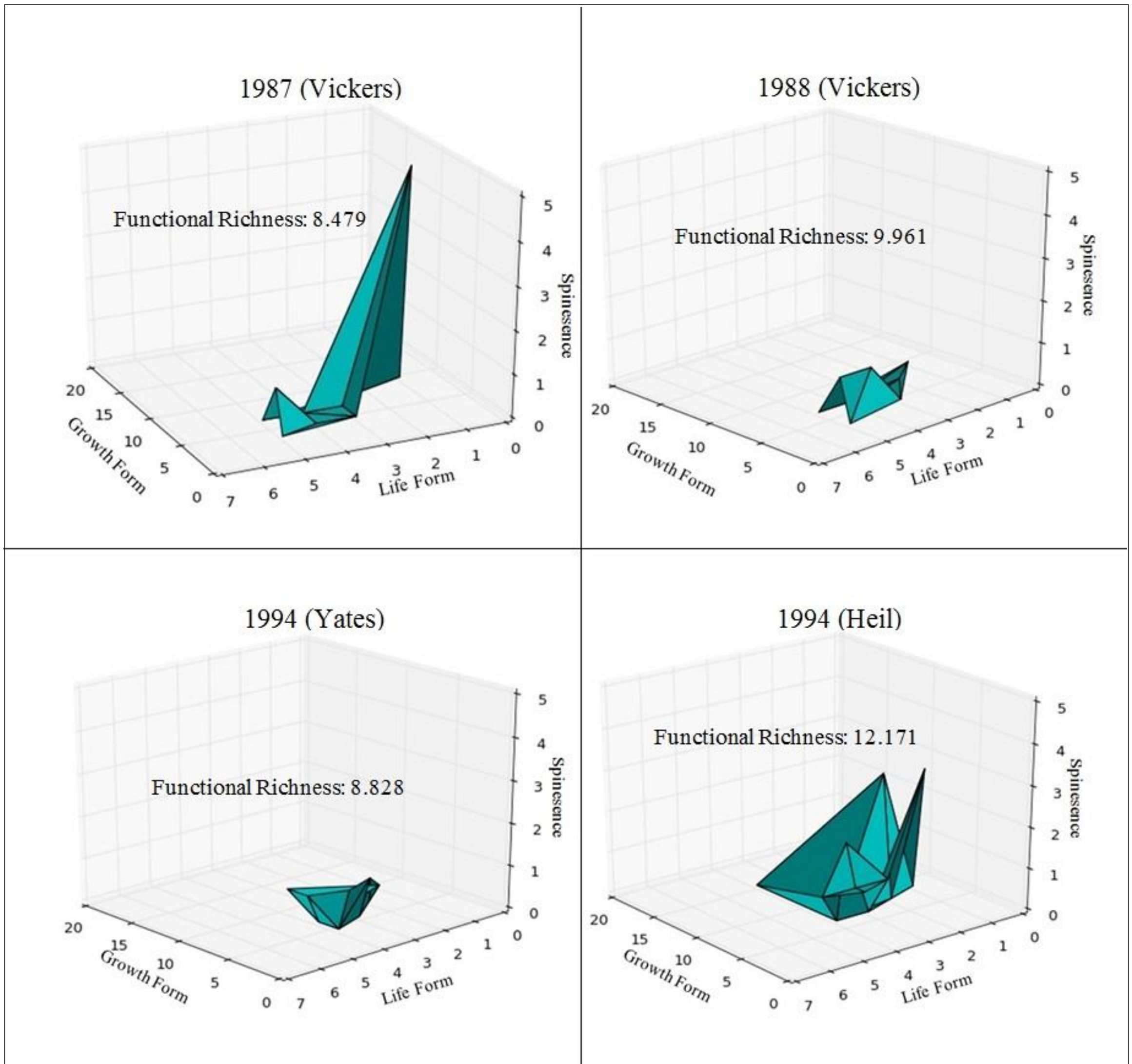

Figure 12. Functional Richness of all samples.

Functional evenness measures the similarity (or evenness) of the Euclidean distance separating pairs of individual species in a sample's functional trait space and is weighted by abundance. Theoretically a more diverse community will be more functionally even and all species will be spread out equally within the trait space and have equal abundances. This measure is incomplete for multiple reasons. The first reason is due to the fact that it measures distances in the functional trait space but does not describe the space itself. The species in a sample could be spread evenly, which would indicate a high level of diversity, but be confined within a small functional trait space. Functional richness is required to understand the scope of functional evenness. The most functionally even sample year was 1988, which also had the second highest functional richness. In tandem, these two indexes seem to indicate that 1988 was one of the most diverse years sampled in this study; however, another weakness of functional evenness is that it does not show the effect of a chronic low level of abundance in the sample. The 1988 sample appears to be diverse because the abundance of nearly all of its species is relatively low. In the case of 1988, evenness is high precisely because so few species have abundances much higher than 10%. When most species in a sample are similar in abundance, the sample will have a higher measure of evenness because weight of abundance is neutralized. Alone, functional evenness falls short as an index because it does not describe the range of trait space in which evenness is spread and it is affected by trends in frequency that encompass the majority of the sample. Awareness of functional evenness's limitations reveals its utility. In a sample with a relatively homogenous series of frequencies, evenness will be a more pure measure of the spread of species in the functional trait space; however, when there is a wide range of frequencies in the sample, evenness can help to understand the distribution of more frequent species in comparison to less frequent species.

Functional divergence measures the divergence of abundance from the center of the sample's functional trait space. The center of the trait space (center of gravity) is based solely on the functional trait space and is not affected by abundance. Functional divergence, like functional evenness, can only be fully understood when functional richness is accounted for. A sample with a high abundance of functionally extreme species will have a low functional divergence if the sample is not functionally rich. The 2014 sample had one of the lowest functional divergences, despite its relatively high functional richness, because the abundance in the sample was grouped closely to the center of gravity. Functional divergence is different from functional evenness because it is a measure of the distance of abundance from the average of all species in the sample as opposed to the distance between pairs of species. A sample could exhibit a high evenness and low divergence if the sample has low richness and relatively similar species frequencies. Functional divergence must be understood in the context of the other FD indexes. A high functional richness creates the potential for a higher level of divergence and functional dispersion can be used to understand how sources of divergence are distributed in the functional trait space. Functional divergence is useful for understanding how abundance of species in a sample is grouped in relation to the average functional trait values of the sample's trait space.

Functional dispersion reveals the dominance of functional niches in the functional trait space. It is similar to divergence because it is an average of Euclidean distance for individual species to a central point. In functional divergence the central point was not affected by species abundance but by the average of the trait values found in the sample. The centroid of functional dispersion is similar to the center of gravity in functional divergence, but it differs in the fact that it gravitates toward abundance. When abundance is dispersed evenly in a functional trait space functional dispersion will be higher and it will be lower when abundance is mostly grouped in a cluster of relatively similar species. The 1988 sample had a high level of evenness due to the high number of relatively infrequent species and high divergence because the two dominating species were highly divergent from the center of gravity; however, the 1988 sample has a low functional dispersion because the two dominant species are functionally similar to each other. The other indexes indicated that the 1988 sample had high biodiversity, but their high scores can only be understood in the light of dispersion. The 1988 sample had a lack of diversity because its abundance was not highly dispersed. Dispersion is useful for understanding the dispersion of dominance in a sample's functional trait space. Like the other indexes it can only be understood in light of functional richness because it is contained within the functional trait space. It should be understood in the light of the other functional diversity indexes.

The four indexes identified by Villeger et al. (2008) and Laliberte and Legendre (2010) help to understand different aspects of FD. Each index has weaknesses and cannot be considered as a complete measure of biodiversity by itself. All four indexes considered in concert reveal a more complete picture of a community's biodiversity.

Functional Traits

Growth form, the first trait measured, is mainly a measure of canopy height and canopy cover (Cornelissen et al. 2003). These can factors can influence an array of different ecosystem interactions. One example of this is herbivory. Grasses and other similar plants are more likely to be food for grazers than tall trees. The first three samples had average growth forms between 5 and 6. A growth form of 5 means that the plant was a cushion; the growth form 6 is a tussock. However, there were very few species that actually had growth forms of 5. The average was mainly influenced by the grasses (which all had growth forms of 6) but was also influenced by the erect leafy forbs (which had growth forms of 4). This is a range of plants that occupies more vertical space than horizontal and is a prime target for grazers. The 2014 sample saw an increase in average growth form. This indicates that there was a larger presence of tall species with wide canopies that are less likely to be grazed and can potentially provide habitats for different species than grasses and forbs would.

The second trait, Life form, is mainly a measure of the relation of a plants meristematic tissue to the ground (Cornellissen et al. 2008). This trait can be informative on how a species responds to external pressures such as grazing or wildfire. Plants with low life form values will have meristematic tissue that is far away from the soil and are more vulnerable to events that destroy the plants above ground tissue. Plants with higher life forms are more likely to survive fires and grazing due to their meristematic tissue that lies close to or below the ground. The average life form in the first three sample years was between 3 and 4 (about the middle of the spectrum). This indicates that most plants in those samples periodically were reduced to either root storage organs or vegetative buds at the surface level. The average life form lowered in the 2014 sample indicating that the community contained more tall plants with meristematic tissue far from the surface (e.g. trees). Because of this, the community is probably more vulnerable to an event such as a wildfire but less likely to be grazed. It is possible that this lowering of life form is due to many years without catastrophic disturbances that would allow for plants such as trees to be established.

The final trait, spinesence, is a measure of the number and severity of spine like structures than can be expected on plants of each species. This trait is largely informative of the plants inherent defensive strategies against herbivory and other animal disturbances. All sample years showed low average spinesence values indicating that the community has always had an overall lack of spines. Since most of the plants found have life forms that allow them to grow back after grazing it is somewhat unnecessary for the average Monahan plant to have defenses against it. The 2014 sample showed an increase in spinesence meaning that the plants found in that sample have more spines. This mirrors the other trait values that show trends away from the more grazer-friendly plant sets found in 1987, 1988, and 1994.

CHAPTER V

CONCLUSION

The Monahan

As expected, the species composition of the Monahan has fluctuated throughout the years. The original seeding had a high number of woody plants which did not prove to be successful on the Monahan. This study does not go far enough to understand what exactly about the Monahan is prohibitive to the functional niches that woody species occupy; however, it can be concluded that they have been historically unsuccessful on the grassland. The most recent vegetative survey shows that woody species have increased in richness on the grassland since the 1996 sample, but remain at low abundances.

All of the samples that have been taken show grasses and forbs to be the most abundant plants on the grassland. In the original seeding only three forb species were seeded. Species richness of forbs has waxed and waned throughout the years, but overall showed a definite increase from the original seeding. The forb species that are the most abundant (e.g. *Melilotus officinalis*, *Solidago* sp.) are of the Raunkiaer classification "erect leafy"; they have long erect stems with leaves distributed relatively evenly throughout (Cornelissen et al., 2003). Forbs with other growth forms never broke the top five most abundant species in a sample year. It is likely that this growth form is better equipped to compete with grasses than other growth forms with leaves closer to the ground.

Grasses were the most consistently dominant type of plants. In every sample they had multiple representatives among the top five most abundant species. Almost all grass species had identical sets of functional trait values. The dominance of grass throughout the years suggests a relatively one dimensional community where only a few functionally similar plants are dominant.

The Monahan has become more functionally diverse over time. The first vegetative sample gave the least diverse picture of the Monahan and the next year the sample showed a higher level of diversity but low species abundance across the board. The 1996 sample had high species abundances and a high dispersion of abundance in its functional trait space. In 2014 the functional richness of the Monahan was high, but diversity in other areas had lessened. Expansion of functional diversity of the Monahan has been manifested in different ways since the original seeding; but it can be concluded that the Monahan reclaimed grassland has a higher level of functional diversity, and by extension biodiversity, than it did in the first year it was sampled.

Biodiversity

Measuring biodiversity is a proposition that has caused controversy and discussion throughout the ecological community. There is not agreement on whether functional diversity is the best approach to understanding biodiversity and the approach to the measurement of biodiversity taken in this study is not standard to the field of ecology. This study was useful in that it highlighted some of the subtle aspects of the FD indexes proposed by Villeger et al. (2008) and Laliberte and Legendre (2010) and confirmed the necessity for utilizing multiple indexes to fully understand the FD of a community.

Recommendations

Most hurdles in this study came from the fact that it is an analysis of three different studies conducted by different students, none of whom intended to collaborate with each other. This will most likely be a issue to all future studies as well. Barriers that arise from this include a lack of uniformity in sampling methods, changes in scientific philosophy and goals, inconsistent intervals between sampling years, and changes in the taxonomy of plants among others. The only way to overcome these issues would be to establish a consistent program of uniform methods for sampling the Monahan.

One of the main issues in this study was the number of functional traits being considered. Describing the diversity of the Monahan by measuring only three functional traits gives an incomplete understanding of the functional niches on the Monahan. A complete account of the functional dynamics of any ecosystem is probably impossible to achieve; however, sampling a higher number of functional traits will yield more data with which to understand FD. The program used in this study, R, would theoretically be sufficient to compute an unlimited number of traits. The nature of this study prohibited the use of functional traits other than the three that were used. Most traits must be measured at the same time the sample is taken and could not be compared to the past surveys. Using the same method of measuring FD, a multi-year comparison that uses a larger number of functional traits would require the traits to be measured during each sample year. If future surveys use similar methodology it would be beneficial to first establish a yearly database of functional trait measurements on the Monahan.

Another issue of this study is its inability to account for the effect of specific disturbances on the Monahan's FD. An external disturbance definitely affects the functional trait composition and abundance of a community and could potentially cause major shifts in FD; however, the measurement of the impact of disturbances was not possible for this study. This issue has multiple facets to it. One problem is the difficulty of compiling all historical data for disturbances on the Monahan. This hurdle is at least partially surmountable; the weather data and some reports exist to make a catalogue of possible disturbances. To measure the impact of a historic disturbance on FD would not be possible. For example, Vickers (1989) records a fire on the Monahan grassland;1 it is possible to say that the fire may have influenced the shift in FD; but the extent of the fire's influence is not measureable. The length of intervals between most sample years makes it impossible to account for all disturbances and their effects on the Monahan; however, it can be said that the Monahan has definitely changed and become more diverse and that this change must be caused by some form of disturbance. In order to understand the change in diversity on the Monahan it is necessary to understand what caused to change. To account for disturbances a consistent and regular program of measurement is necessary.

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APPENDIX

APPENDIX A - Functional Diversity Values by year

Trait Value Matrix 1981 (Vickers 1989)			
	Growth Form	Life Form	Spinesence
Ambrosia artemisiifolia	4	5	1
Andropogon gerardii	6	4	0
Bouteloua curtipendula	6	3	0
Conyza Canadensis	4	5	1
Dalea candida	4	4	0
Dalea purpurea	4	3	0
Echinochloa crus-galli	6	5	0
Elaeagnus umbellata	8	1	5
Helianthus annuus	4	5	1
Iva annua	4	5	1
Melilotus officinalis	4	5	0
Pascopyrum smithii	6	4	0
Panicum virgatum	6	3	0
Populus deltoids	9	1	0
Setaria parviflora	6	4	1
Sorghastrum nutans	6	4	0
Schizachyrium scoparium	6	3	0
Symphyotrichum subulatum	3	5	0
Solidago Sp.	4	3	1

APPENDIX A - Functional Diversity Values by year (cont.)

Trait Value Matrix 1988 (Vickers, 1989)			
	Growth Form	Life Form	Spinesence
Ambrosia artemisiifolia	4	5	1
Andropogon gerardii	6	4	0
Bouteloua curtipendula	6	3	0
Bouteloua dactyloides	6	3	0
Dalea purpurea	4	3	0
Desmanthus illinoensis	7	2	0
Echinochloa crus-galli	6	5	0
Helianthus annuus	4	5	1
Helianthus maximiliani	4	4	1
Iva annua	4	5	1
Melilotus officinalis	4	5	0
Pascopyrum smithii	6	4	0
Panicum virgatum	6	3	0
Setaria parviflora	6	4	1
Solanum carolinense	4	4	2
Sorghastrum nutans	6	4	0
Schizachyrium scoparium	6	3	0
Symphyotrichum subulatum	3	5	0
Soldigao Sp.	4	3	1

APPENDIX A - Functional Diversity Values by year (cont.)

Trait Value Matrix 1994 (Yates, 1996)			
	Growth Form	Life Form	Spinesence
Ageratina altissima	4	3	0
Achillea millefolium	4	3	1
Acalypha virginica	4	5	1
Andropogon gerardii	6	4	0
Bouteloua curtipendula	6	3	0
Bouteloua dactyloides	6	3	0
Conyza Canadensis	4	5	1
Cornus dromundii	9	1	0
Dalea purpurea	4	3	0
Desmanthus illinoensis	7	2	0
Euthamia gymnospermoides	4	3	0
Erigeron strigosus	4	3	0
Festuca pratensis	6	3	0
Gaura biennis	3	4	1
Geum vernum	3	4	1
Helianthus maximiliani	4	4	1
Oxalis dillenii	5	3	0
Poa pratensis	6	4	0
Panicum capillare	6	5	1
Pascopyrum smithii	6	4	0
Pycnanthemum tenuifolium	4	4	0
Panicum virgatum	6	3	0
Populus deltoids	9	1	0
Physalis longifolia	3	4	0
Ratibida pinnata	4	4	1
Sorghastrum nutans	6	4	0
Symphyotrichum pilosum	4	4	1
Schizachyrium scoparium	6	3	0
Solidago Canadensis	4	3	1
Sporobolus aspera	6	3	0
Sphenopholis obtusata	6	3	0
Tripsacum dactyloides	6	4	0

APPENDIX A - Functional Diversity Values by year (cont.

Trait Value Matrix 2014			
	Growth Form	Life Form	Spinesence
Ambrosia artemisiifolia	4	5	1
Andropogon gerardii	6	4	0
Bouteloua curtipendula	6	3	0
Bouteloua dactyloides	6	3	0
Conyza Canadensis	4	5	1
Cirsium altissimum	4	3	3
Cornus amomum	8	1	0
Cornus dromundii	9	1	0
Desmanthus illinoensis	7	2	0
Eupatorium altissimum	4	4	1
Helianthus maximiliani	4	4	1
Melilotus officinalis	4	5	0
Oenothera villosa	4	4	1
Passiflora incarnata L.	15	4	0
Pascopyrum smithii	6	4	0
Pycnanthemum tenuifolium	4	4	0
Panicum virgatum	6	3	0
Populus deltoids	9	1	0
Physalis heteropylla	3	4	1
Rhus copallina	9	1	0
Rubus flagellaris	7	1	3
Rhus glabra	9	1	0
Rubus occidentalis	8	2	3
Rubus ostryifolius	8	2	3
Solanum dimidiatum	5	4	2
Sorghastrum nutans	6	4	0
Schizachyrium scoparium	6	3	0
Solidago Sp.	4	3	1
Symphoricarpos orbiculatus	8	1	0

APPENDIX B –Latitude and longitude of sampling plots

Sampling Plot 1		
Corner	Latitude	Longitude
NW	37.35344001426	-94.80787100000
SW	37.35298948572	-94.80787100000
SE	37.35298948572	-94.80730665642
NE	37.35344001426	-94.80730665642

Sampling Plot 2		
Corner	Latitude	Longitude
NW	37.35344001426	-94.80730665642
SW	37.35298948572	-94.80730665642
SE	37.35298949998	-94.80674231284
NE	37.35344000002	-94.80674230947

Sampling Plot 3		
Corner	Latitude	Longitude
NW	37.35298948572	-94.80730665642
SW	37.35253897141	-94.80730670013
SE	37.35253898567	-94.80674229996
NE	37.35298949998	-94.80674231284

Sampling Plot 4		
Corner	Latitude	Longitude
NW	37.35253897141	-94.80730670013
SW	37.35208845706	-94.80730670013
SE	37.35163794268	-94.80674229996
NE	37.35253898567	-94.80674229996

Sampling Plot 5		
Corner	Latitude	Longitude
NW	37.35208845706	-94.80730670013
SW	37.35163794268	-94.80730670013
SE	37.35118742826	-94.80674229996
NE	37.35208847132	-94.80674229996

Sampling Plot 6		
Corner	Latitude	Longitude
NW	37.35163794268	-94.80730670013
SW	37.35118742826	-94.80730670013
SE	37.35118742826	-94.80674229996
NE	37.35163794268	-94.80674229996

Sampling Plot 7		
Corner	Latitude	Longitude
NW	37.35298949998	-94.80674231284
SW	37.35253898567	-94.80674229996
SE	37.35253898567	-94.80617796926
NE	37.35298949998	-94.80617796926

Sampling Plot 8		
Corner	Latitude	Longitude
NW	37.35253898567	-94.80674229996
SW	37.35208847132	-94.80674229996
SE	37.35208847132	-94.80617796926
NE	37.35253898567	-94.80617796926

Sampling Plot 9		
Corner	Latitude	Longitude
NW	37.35208847132	-94.80674229996
SW	37.35163794268	-94.80674229996
SE	37.35163794268	-94.80617796926
NE	37.35208847132	-94.80617796926

Sampling Plot 10		
Corner	Latitude	Longitude
NW	37.35163794268	-94.80674229996
SW	37.35118742826	-94.80674229996
SE	37.35118742826	-94.80617796926
NE	37.35163794268	-94.80617796926

Sampling Plot 11		
Corner	Latitude	Longitude
NW	37.35118742826	-94.80674229996
SW	37.35073691381	-94.80674229996
SE	37.35073691381	-94.80617796926
NE	37.35118742826	-94.80617796926

Sampling Plot 12		
Corner	Latitude	Longitude
NW	37.35298949998	-94.80617796926
SW	37.35253898567	-94.80617796926
SE	37.35253898567	-94.80561362568
NE	37.35298949998	-94.80561362568

APPENDIX B (cont.) –Latitude and longitude of sampling plots

Sampling Plot 13		
Corner	Latitude	Longitude
NW	37.35253898567	-94.80617796926
SW	37.35208847132	-94.80617796926
SE	37.35208847132	-94.80561362568
NE	37.35253898567	-94.80561362568

Sampling Plot 14		
Corner	Latitude	Longitude
NW	37.35208847132	-94.80617796926
SW	37.35163794268	-94.80617796926
SE	37.35163794268	-94.80561362568
NE	37.35208847132	-94.80561362568

Sampling Plot 15		
Corner	Latitude	Longitude
NW	37.35163794268	-94.80617796926
SW	37.35118742826	-94.80617796926
SE	37.35118742826	-94.80561362568
NE	37.35163794268	-94.80561362568

Sampling Plot 16		
Corner	Latitude	Longitude
NW	37.35118742826	-94.80617796926
SW	37.35073691381	-94.80617796926
SE	37.35073691381	-94.80561362568
NE	37.35118742826	-94.80561362568

Sampling Plot 17		
Corner	Latitude	Longitude
NW	37.35073691381	-94.80617796926
SW	37.35028639933	-94.80617796926
SE	37.35028639933	-94.80561362568
NE	37.35073691381	-94.80561362568

Sampling Plot 18		
Corner	Latitude	Longitude
NW	37.35298949998	-94.80561362568
SW	37.35253898567	-94.80561362568
SE	37.35253899998	-94.80504928547
NE	37.35298949998	-94.80504928210

Sampling Plot 19		
Corner	Latitude	Longitude
NW	37.35298949998	-94.80561362568
SW	37.35253898567	-94.80561362568
SE	37.35253899998	-94.80504928547
NE	37.35298949998	-94.80504928210

Sampling Plot 20		
Corner	Latitude	Longitude
NW	37.35253898567	-94.80561362568
SW	37.35208847132	-94.80561362568
SE	37.35208847132	-94.80504928547
NE	37.35253899998	-94.80504928547

Sampling Plot 21		
Corner	Latitude	Longitude
NW	37.35208847132	-94.80561362568
SW	37.35163794268	-94.80561362568
SE	37.35163794268	-94.80504928547
NE	37.35208847132	-94.80504928547

Sampling Plot 22		
Corner	Latitude	Longitude
NW	37.35163794268	-94.80561362568
SW	37.35118742826	-94.80561362568
SE	37.35118742826	-94.80504928547
NE	37.35163794268	-94.80504928547

Sampling Plot 23		
Corner	Latitude	Longitude
NW	37.35118742826	-94.80561362568
SW	37.35073691381	-94.80561362568
SE	37.35073691381	-94.80504928547
NE	37.35118742826	-94.80504928547

Sampling Plot 24		
Corner	Latitude	Longitude
NW	37.35073691381	-94.80561362568
SW	37.35028639933	-94.80561362568
SE	37.35028639933	-94.80504928547
NE	37.35073691381	-94.80504928547

APPENDIX B (cont.) –Latitude and longitude of sampling plots

Sampling Plot 25		
Corner	Latitude	Longitude
NW	37.35028639933	-94.80561362568
SW	37.34983588481	-94.80561359992
SE	37.34983588481	-94.80504928547
NE	37.35028639933	-94.80504928547

Sampling Plot 31		
Corner	Latitude	Longitude
NW	37.35073691381	-94.80504928547
SW	37.35028639933	-94.80504928547
SE	37.35028639933	-94.80448494526
NE	37.35073691381	-94.80448494526

Sampling Plot 26		
Corner	Latitude	Longitude
NW	37.35298949998	-94.80504928210
SW	37.35253899998	-94.80504928547
SE	37.35253899998	-94.80448494526
NE	37.35298949998	-94.80448494526

Sampling Plot 32		
Corner	Latitude	Longitude
NW	37.35028639933	-94.80504928547
SW	37.34983588481	-94.80504928547
SE	37.34983588481	-94.80448494526
NE	37.35028639933	-94.80448494526

Sampling Plot 27		
Corner	Latitude	Longitude
NW	37.35253899998	-94.80504928547
SW	37.35208847132	-94.80504928547
SE	37.35208847132	-94.80448494526
NE	37.35253899998	-94.80448494526

Sampling Plot 33		
Corner	Latitude	Longitude
NW	37.35298949998	-94.80448494526
SW	37.35253899998	-94.80448494526
SE	37.35253899998	-94.80392060168
NE	37.35298949998	-94.80392060168

Sampling Plot 28		
Corner	Latitude	Longitude
NW	37.35208847132	-94.80504928547
SW	37.35163794268	-94.80504928547
SE	37.35163794268	-94.80448494526
NE	37.35208847132	-94.80448494526

Sampling Plot 34		
Corner	Latitude	Longitude
NW	37.35253899998	-94.80448494526
SW	37.35208847132	-94.80448494526
SE	37.35208847132	-94.80392060168
NE	37.35253899998	-94.80392060168

Sampling Plot 29		
Corner	Latitude	Longitude
NW	37.35163794268	-94.80504928547
SW	37.35118742826	-94.80504928547
SE	37.35118742826	-94.80448494526
NE	37.35163794268	-94.80448494526

Sampling Plot 35		
Corner	Latitude	Longitude
NW	37.35208847132	-94.80448494526
SW	37.35163794268	-94.80448494526
SE	37.35163794268	-94.80392060168
NE	37.35208847132	-94.80392060168

Sampling Plot 30		
Corner	Latitude	Longitude
NW	37.35118742826	-94.80504928547
SW	37.35073691381	-94.80504928547
SE	37.35073691381	-94.80448494526
NE	37.35118742826	-94.80448494526

Sampling Plot 36		
Corner	Latitude	Longitude
NW	37.35163794268	-94.80448494526
SW	37.35118742826	-94.80448494526
SE	37.35118742826	-94.80392060168
NE	37.35163794268	-94.80392060168

APPENDIX B (cont.) –Latitude and longitude of sampling plots

Sampling Plot 37		
Corner	Latitude	Longitude
NW	37.35118742826	-94.80448494526
SW	37.35073691381	-94.80448494526
SE	37.35073691381	-94.80392060168
NE	37.35118742826	-94.80392060168

Sampling Plot 38		
Corner	Latitude	Longitude
NW	37.35073691381	-94.80448494526
SW	37.35028639933	-94.80448494526
SE	37.35028639933	-94.80392060168
NE	37.35073691381	-94.80392060168

Sampling Plot 39		
Corner	Latitude	Longitude
NW	37.35028639933	-94.80448494526
SW	37.34983588481	-94.80448494526
SE	37.34983588481	-94.80392060168
NE	37.35028639933	-94.80392060168

Sampling Plot 40		
Corner	Latitude	Longitude
NW	37.35298949998	-94.80392060168
SW	37.35253899998	-94.80392060168
SE	37.35253899998	-94.80335625810
NE	37.35298949998	-94.80335625810

Sampling Plot 41		
Corner	Latitude	Longitude
NW	37.35253899998	-94.80392060168
SW	37.35208847132	-94.80392060168
SE	37.35208847132	-94.80335625810
NE	37.35253899998	-94.80335625810

Sampling Plot 42		
Corner	Latitude	Longitude
NW	37.35208847132	-94.80392060168
SW	37.35163794268	-94.80392060168
SE	37.35163794268	-94.80335625810
NE	37.35208847132	-94.80335625810

Sampling Plot 43		
Corner	Latitude	Longitude
NW	37.35163794268	-94.80392060168
SW	37.35118742826	-94.80392060168
SE	37.35118742826	-94.80335625810
NE	37.35163794268	-94.80335625810

Sampling Plot 44		
Corner	Latitude	Longitude
NW	37.35118742826	-94.80392060168
SW	37.35073691381	-94.80392060168
SE	37.35073691381	-94.80335625810
NE	37.35118742826	-94.80335625810

Sampling Plot 45		
Corner	Latitude	Longitude
NW	37.35073691381	-94.80392060168
SW	37.35028639933	-94.80392060168
SE	37.35028639933	-94.80335625810
NE	37.35073691381	-94.80335625810

APPENDIX C – Raw data by plot and quadrat

Plot 1; Quadrat 1	% cover
Cornus amomum	45
Rhus copallina	28
Melilotus officinalis	15
Panicum virgatum	3
Conyza canadensis	3

Plot 1; Quadrat 2	% cover
Conyza canadensis	8
Cornus amomum	15
Desmanthus illinoensis	15
Rhus copallina	55
Bouteloua curtipendula	35
Panicum virgatum	15

Plot 1; Quadrat 3	% cover
Cornus amomum	50
Conyza canadensis	10
Panicum virgatum	40
Bouteloua curtipendula	35
Panicum virgatum	7

Plot 1; Quadrat 4	% cover
Melilotus officinalis	35
Panicum virgatum	17
Cornus amomum	10
Desmanthus illinoensis	3
Conyza canadensis	7
Bouteloua curtipendula	3
Symphoricarpos orbiculatu	25

Plot 1; Quadrat 5	% cover
Cornus amomum	10
Melilotus officinalis	60
Conyza canadensis	10
Panicum virgatum	15
Bouteloua curtipendula	50
Schizachyrium scoparius	5

Plot 2; Quadrat 1	% cover
Panicum virgatum	100
Bouteloua dactyloides	50

Plot 2; Quadrat 2	% cover
Panicum virgatum	100
Bouteloua dactyloides	30
Melilotus officinalis	1

Plot 2; Quadrat 3	% cover
Panicum virgatum	100
Bouteloua dactyloides	50

Plot 2; Quadrat 4	% cover
Panicum virgatum	100
Bouteloua dactyloides	30
Conyza canadensis	50

Plot 2; Quadrat 5	% cover
Panicum virgatum	100
Bouteloua dactyloides	50

APPENDIX C (cont.) – Raw data by plot and quadrat

Plot 3; Quadrat 1	% cover
Panicum virgatum	60
Conyza canadensis	50
Solidago sp.	11
Melilotus officinalis	30

Plot 3; Quadrat 2	% cover
Panicum virgatum	90
Melilotus officinalis	30
Pycnanthemum tenuifolium	15

Plot 3; Quadrat 3	% cover
Panicum virgatum	90
Conyza canadensis	50

Plot 3; Quadrat 4	% cover
Panicum virgatum	50
Conyza canadensis	40
Solidago sp.	10
Bouteloua dactyloides	30

Plot 3; Quadrat 5	% cover
Panicum virgatum	90
Conyza canadensis	30
Solidago sp.	3

Plot 4; Quadrat 1	% cover
Panicum virgatum	100
Melilotus officinalis	1

Plot 4; Quadrat 2	% cover
Panicum virgatum	75
Bouteloua curtipendula	15
Schizachyrium scoparium	8
Eupatorium altissimum	20
Pycnanthemum tenuifolium	1

Plot 4; Quadrat 3	% cover
Bouteloua curtipendula	60
Eupatorium altissimum	10
Helianthus maximiliani	1
Conyza canadensis	5
Melilotus officinalis	30
Rubus Flagellaris	10

Plot 4; Quadrat 4	% cover
Panicum virgatum	5
Andropogon gerardii	5
Melilotus officinalis	40
Rhus copallina	5
Cornus dromundii	60

Plot 4; Quadrat 5	% cover
Panicum virgatum	60
Melilotus officinalis	1
Cornus amomum	30
Populus deltoides	90

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 5; Quadrat 1	% cover
Melilotus officinalis	40
Bouteloua dactyloides	30
Cornus ammomum	30
Pycnanthemum tenuifolium	1

Plot 5; Quadrat 2	% cover
Melilotus officinalis	40
Bouteloua curtipendula	30
Panicum virgatum	5

Plot 5; Quadrat 3	% cover
Panicum virgatum	60
Melilotus officinalis	20
Andropogon gerardii	50
Sorghastrum nutans	10
Glandularia bipinnitifida	1

Plot 5; Quadrat 4	% cover
Panicum virgatum	70
Melilotus officinalis	60
Sorghastrum nutans	30
Eupatorium altissimum	1
Passiflora incarnata L.	5
Solidago missouriensis	5
Solidago gigantea	1

Plot 5; Quadrat 5	% cover
Melilotus officinalis	40
Panicum virgatum	90
Bouteloua curtipendula	10

Plot 6; Quadrat 1	% cover
Panicum virgatum	100

Plot 6; Quadrat 2	% cover
Panicum virgatum	5
Melilotus officinalis	60
Solidago missouriensis	50
Glandularia bipinnitifida	1
Cirsium altissimum	1

Plot 6; Quadrat 3	% cover
Panicum virgatum	10

Plot 6; Quadrat 4	% cover
Panicum virgatum	100
Cornus drumondii	20
Glandularia bipinnitifida	1

Plot 6; Quadrat 5	% cover
Panicum virgatum	95

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 7; Quadrat 1	% cover
Panicum virgatum	100
Bouteloua dactyloides	50
Solidago missouriensis	10

Plot 7; Quadrat 2	% cover
Panicum virgatum	20
Solidago missouriensis	10
Solidago gigantia	5
Melilotus officinalis	1

Plot 7; Quadrat 3	% cover
Panicum virgatum	100
Bouteloua dactyloides	15

Plot 7; Quadrat 4	% cover
Panicum virgatum	10
Solidago missouriensis	10

Plot 7; Quadrat 5	% cover
Panicum virgatum	20
Melilotus officinalis	70
Helianthus maximiliani	1
Solidago gigantia	10

Plot 8; Quadrat 1	% cover
Panicum virgatum	60
Solidago missouriensis	30
Cornus dromundii	50

Plot 8; Quadrat 2	% cover
Panicum virgatum	20
Solidago missouriensis	10
Bouteloua dactyloides	70
Melilotus officinalis	15

Plot 8; Quadrat 3	% cover
Panicum virgatum	40
Solidago missouriensis	50
Solidago gigantia	10
Melilotus officinalis	70
Schizachyrium scoparium	20

Plot 8; Quadrat 4	% cover
Andropogon gerardii	50
Solidago missouriensis	30
Solidago gigantia	5
Melilotus officinalis	15
Desmanthus illinoensis	5
Pycnanthemum tenuifolium	1

Plot 8; Quadrat 5	% cover
Schizachyrium scoparium	70
Solidago missouriensis	40
Melilotus officinalis	60
Solidago gigantia	1
Pycnanthemum tenuifolium	5

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 9; Quadrat 1	% cover
Panicum virgatum	60
Solidago missouriensis	40
Pycnanthemum tenuifolium	20
Melilotus officinalis	50

Plot 9; Quadrat 2	% cover
Melilotus officinalis	80
Panicum virgatum	20
Solidago missouriensis	50
Glandularia bipinnitifida	1

Plot 9; Quadrat 3	% cover
Cornus dromundii	10
Solidago missouriensis	30
Sorghastrum nutans	5
Panicum virgatum	10
Schizachyrium scoparium	70
Solidago missouriensis	10
Pycnanthemum tenuifolium	15
Melilotus officinalis	5

Plot 9; Quadrat 4	% cover
Panicum virgatum	40
Sorghastrum nutans	40
Solidago missouriensis	30
Pycnanthemum tenuifolium	50
Helianthus maximiliani	1

Plot 9; Quadrat 5	% cover
Panicum virgatum	70
Melilotus officinalis	40
Solidago missouriensis	20

Plot 10; Quadrat 1	% cover
Panicum virgatum	60
Melilotus officinalis	40
Solidago missouriensis	5

Plot 10; Quadrat 2	% cover
Melilotus officinalis	40

Plot 10; Quadrat 3	% cover
Solidago missouriensis	60
Melilotus officinalis	10
Panicum virgatum	5
Schizachyrium Scoparium	60

Plot 10; Quadrat 4	% cover
Melilotus officinalis	50
Solidago missouriensis	30
Pycnanthemum tenuifolium	30
Panicum virgatum	20
Sideoats grama	20

Plot 10; Quadrat 5	% cover
Panicum virgatum	50
Melilotus officinalis	80
Solidago missouriensis	60
Pycnanthemum tenuifolium	20

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 11; Quadrat 1	% cover
Glandularia bipinnitifida	20
Melilotus officinalis	70
Panicum virgatum	20
Solidago missouriensis	20
Helianthus maximiliani	5

Plot 11; Quadrat 2	% cover
Panicum virgatum	50
Melilotus officinalis	70
Solidago missouriensis	30
Solidago gigantia	10
Glandularia bipinnitifida	1

Plot 11; Quadrat 3	% cover
Bouteloua curtipendula	10
Panicum virgatum	30
Melilotus officinalis	80
Glandularia bipinnitifida	1

Plot 11; Quadrat 4	% cover
Panicum virgatum	10
Melilotus officinalis	60
Solidago missouriensis	30
Cornus amomum	10
Rubus flagellaris	50

Plot 11; Quadrat 5	% cover
Andropogon gerardii	40
Solidago missouriensis	20
Melilotus officinalis	10
Helianthus maximiliani	15

Plot 12; Quadrat 1	% cover
Melilotus officinalis	90
Schizachyrium scoparium	20
Sorghastrum nutans	1
Andropogon gerardii	60
Solidago missouriensis	15
Eupatorium altissimum	15

Plot 12; Quadrat 2	% cover
Glandularia bipinnitifida	1
Schizachyrium scoparium	80
Melilotus officinalis	1
Eupatorium altissimum	1
Bouteloua curtipendula	*10*

Plot 12; Quadrat 3	% cover
Panicum virgatum	20
Andropogon gerardii	60
Solidago missouriensis	70
Melilotus officinalis	30
Solidago sp.	15

Plot 12; Quadrat 4	% cover
Andropogon gerardii	50
Panicum virgatum	50
Eupatorium altissimum	5
Cornus amomum	10
Conyza canadensis	1
Rubus ostryifolius	5

Plot 12; Quadrat 5	% cover
Bouteloua curtipendula	50
Melilotus officinalis	50
Solidago missouriensis	20
Helianthus maximiliani	1

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 13; Quadrat 1	% cover
Solidago missouriensis	50
Melilotus officinalis	90
Panicum virgatum	40
Pycnanthemum tenuifolium	1

Plot 13; Quadrat 2	% cover
Panicum virgatum	50
Melilotus officinalis	80
Solidago missouriensis	20

Plot 13; Quadrat 3	% cover
Solidago missouriensis	70
Andropogon gerardii	30

Plot 13; Quadrat 4	% cover
Solidago missouriensis	30
Melilotus officinalis	80
Panicum virgatum	5
Andropogon gerardii	5

Plot 13; Quadrat 5	% cover
Solidago missouriensis	30
Melilotus officinalis	90
Panicum virgatum	40
Pycnanthemum tenuifolium	1

Plot 14; Quadrat 1	% cover
Panicum virgatum	70
Sorghastrum nutans	10
Solidago missouriensis	5
Solidago gigantia	5
Melilotus officinalis	70
Pycnanthemum tenuifolium	1

Plot 14; Quadrat 2	% cover
Panicum virgatum	95
Melilotus officinalis	20
Solidago missouriensis	20
Eupatorium altissimum	1

Plot 14; Quadrat 3	% cover
Panicum virgatum	50
Melilotus officinalis	90
Solidago missouriensis	40
Eupatorium altissimum	30

Plot 14; Quadrat 4	% cover
Panicum virgatum	5
Solidago missouriensis	10
Melilotus officinalis	50
Cornus amomum	1
Sideaoats grama	60

Plot 14; Quadrat 5	% cover
Melilotus officinalis	90
Bouteloua curtipendula	5
Andropogon gerardii	5
Solidago missouriensis	40

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 15; Quadrat 1	% cover
Sorghastrum nutans	15
Andropogon gerardii	80
Panicum virgatum	5
Melilotus officinalis	10
Helianthus maximiliani	1

Plot 15; Quadrat 2	% cover
Melilotus officinalis	50
Solidago missouriensis	30
Eupatorium altissimum	20
Panicum virgatum	70

Plot 15; Quadrat 3	% cover
Glandularia bipinnitifida	70
Solidago missouriensis	30
Eupatorium altissimum	5
Melilotus officinalis	10

Plot 15; Quadrat 4	% cover
Melilotus officinalis	70
Rubus Flagellaris	30
Solidago missouriensis	50
Panicum virgatum	25

Plot 15; Quadrat 5	% cover
Panicum virgatum	40
Melilotus officinalis	100
Eupatorium altissimum	1

Plot 16; Quadrat 1	% cover
Melilotus officinalis	50
Eupatorium altissimum	30
Andropogon gerardii	90

Plot 16; Quadrat 2	% cover
Rhus copallina	60
Melilotus officinalis	60
Panicum virgatum	60
Solidago missouriensis	30

Plot 16; Quadrat 3	% cover
Solidago missouriensis	15
Andropogon gerardii	90
Melilotus officinalis	50

Plot 16; Quadrat 4	% cover
Melilotus officinalis	90
Panicum virgatum	60

Plot 16; Quadrat 5	% cover
Eupatorium altissimum	10
Solidago missouriensis	10
Melilotus officinalis	80
Rhus copallina	40
Panicum virgatum	70

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 17; Quadrat 1	% cover
Panicum virgatum	90
Melilotus officinalis	50
Solidago missouriensis	50

Plot 17; Quadrat 2	% cover
Panicum virgatum	90
Pycnanthemum tenuifolium	40
Melilotus officinalis	60
Solidago missouriensis	50

Plot 17; Quadrat 3	% cover
Sorghastrum nutans	30
Panicum virgatum	30
Bouteloua curtipendula	30
Agropyron smithii	5
Melilotus officinalis	30
Solidago missouriensis	1
Helianthus maximiliani	1

Plot 17; Quadrat 4	% cover
Panicum virgatum	90
Pycnanthemum tenuifolium	40
Melilotus officinalis	60
Solidago missouriensis	50

Plot 17; Quadrat 5	% cover
Panicum virgatum	30
Solidago missouriensis	40
Bouteloua curtipendula	30
Pycnanthemum tenuifolium	5
Melilotus officinalis	20

Plot 18; Quadrat 1	% cover
Solidago missouriensis	50
Panicum virgatum	15
Eupatorium altissimum	1

Plot 18; Quadrat 2	% cover
Rhus copallina	100
Solidago missouriensis	50
Panicum virgatum	50

Plot 18; Quadrat 3	% cover
Solidago missouriensis	30
Eupatorium altissimum	10
Melilotus officinalis	40
Glandularia bipinnitifida	15
Andropogon gerardii	50

Plot 18; Quadrat 4	% cover
Bouteloua curtipendula	90
Melilotus officinalis	1
Solidago missouriensis	10
Melilotus officinalis	30
Rhus glabra	20

Plot 18; Quadrat 5	% cover
Bouteloua curtipendula	80
Melilotus officinalis	5
Rubus ostryifolius	5
Rhus glabra	100

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 19; Quadrat 1	% cover
Melilotus officinalis	50
Schizachyrium scoparium	50

Plot 19; Quadrat 2	% cover
Rhus aromatica	60

Plot 19; Quadrat 3	% cover
Rhus aromatica	100

Plot 19; Quadrat 4	% cover
Solidago missouriensis	90
Eupatorium altissimum	10
Schizachyrium scoparium	10

Plot 19; Quadrat 5	% cover
Solidago missouriensis	30
Melilotus officinalis	40
Panicum virgatum	60

Plot 20; Quadrat 1	% cover
Andropogon gerardii	80
Melilotus officinalis	10
Solidago missouriensis	10
Agropyron smithii	1

Plot 20; Quadrat 2	% cover
Rhus aromatica	50
Cornus amomum	30
Schizachyrium scoparium	50
Solidago missouriensis	10
Melilotus offcinalis	15

Plot 20; Quadrat 3	% cover
Sorghastrum nutans	10
Melilotus officinalis	90
Solidago missouriensis	20
Panicum virgatum	10

Plot 20; Quadrat 4	% cover
Physalis longifolia	60

Plot 20; Quadrat 5	% cover
Rhus copallina	100
Bouteloua dactyloides	90
Solidago missouriensis	15
Symphocarpos orbiculatus	10

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 21; Quadrat 1	% cover
Panicum virgatum	90
Solidago missouriensis	40
Melilotus officinalis	10

Plot 21; Quadrat 2	% cover
Panicum virgatum	1
Solidago missouriensis	15
Melilotus officinalis	90

Plot 21; Quadrat 3	% cover
Eupatorium altissimum	60
Sorghastrum nutans	90
Solidago missouriensis	15
Symphocarpos orbiculatus	10

Plot 21; Quadrat 4	% cover
Rhus aromatica	100

Plot 21; Quadrat 5	% cover
Rhus copallina	80
Bouteloua dactyloides	90

Plot 22; Quadrat 1	% cover
Symphocarpos orbiculatus	90
Panicum virgatum	5
Melilotus officinalis	90

Plot 22; Quadrat 2	% cover
Melilotus officinalis	100
Andropogon gerardii	15

Plot 22; Quadrat 3	% cover
Melilotus officinalis	95
Sorghastrum nutans	60

Plot 22; Quadrat 4	% cover
Melilotus officinalis	100
Sorghastrum nutans	15
Bouteloua curtipendula	1
Andropogon gerardii	1

Plot 22; Quadrat 5	% cover
Melilotus officinalis	60
Panicum virgatum	50
Solidago missouriensis	30
Helianthus maximiliani	20

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 23; Quadrat 1	% cover
Melilotus officinalis	90
Solidago missouriensis	20
Sorghastrum nutans	10
Andropogon gerardii	5
Bouteloua curtipendula	15
Pancium virgatum	5
Panicum virgatum	1

Plot 23; Quadrat 2	% cover
Sorghum halepnse	80
Sorghastrum nutans	50
Eupatorium altissimum	1
Solidago missouriensis	1
Melilotus offcinalis	80

Plot 23; Quadrat 3	% cover
Melilotus officinalis	90
Solidago missouriensis	1
Sorghastrum nutans	1
Andropogon gerardii	1
Panicum virgatum	5
Pancium virgatum	5

Plot 23; Quadrat 4	% cover
Panicum virgatum	70
Sorghastrum nutans	70
Pycnanthemum tenuifolium	15
Solidago missouriensis	5
Melilotus offcinalis	40

Plot 23; Quadrat 5	% cover
Panicum virgatum	10
Sorghastrum nutans	5
Pycnanthemum tenuifolium	10
Solidago missouriensis	15
Melilotus offcinalis	90

Plot 24; Quadrat 1	% cover
Panicum virgatum	80
Melilotus officinalis	100
Solidago missouriensis	10
Glandularia bipinnitifida	1

Plot 24; Quadrat 2	% cover
Panicum virgatum	90
Solidago missouriensis	10
Melilotus officinalis	60

Plot 24; Quadrat 3	% cover
Andropogon gerardii	20
Sorghastrum nutans	40
Sorghum halpense	10
Solidago missouriensis	10
Melilotus offcinalis	100

Plot 24; Quadrat 4	% cover
Cornus dromundii	10
Sorghastrum nutans	15
Sorghum halpense	50
Solidago missouriensis	10
Melilotus offcinalis	100

Plot 24; Quadrat 5	% cover
Glandularia bipinnitifida	15
Sorghastrum nutans	10
Sorghum halpense	70
Solidago missouriensis	10
Melilotus offcinalis	90

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 25; Quadrat 1	% cover
Solidago missouriensis	90
Panicum virgatum	80
Melilotus officinalis	10

Plot 25; Quadrat 2	% cover
Panicum virgatum	80
Melilotus officinalis	60
Solidago missouriensis	40
Sorghastrum nutans	30

Plot 25; Quadrat 3	% cover
Panicum virgatum	70
Melilotus officinalis	70
Solidago missouriensis	10
Sorghastrum nutans	20

Plot 25; Quadrat 4	% cover
Sorghastrum nutans	1
Melilotus officinalis	50
Solidago missouriensis	30
Sorghastrum nutans	30

Plot 25; Quadrat 5	% cover
Panicum virgatum	5
Melilotus officinalis	10
Solidago missouriensis	50
Sorghastrum nutans	10

Plot 26; Quadrat 1	% cover
Solidago missouriensis	70
Sorghastrum nutans	15
Panicum virgatum	15

Plot 26; Quadrat 2	% cover
Solidago missouriensis	60
Sorghastrum nutans	20
Panicum virgatum	70

Plot 26; Quadrat 3	% cover
Panicum virgatum	20
Melilotus officinalis	10
Solidago missouriensis	70
Sorghastrum nutans	50

Plot 26; Quadrat 4	% cover
Panicum virgatum	60
Melilotus officinalis	5
Solidago missouriensis	80
Eupatorium altissimum	5

Plot 26; Quadrat 5	% cover
Solidago missouriensis	15
Sorghastrum nutans	60
Melilotus officinalis	15
Panicum virgatum	5
Andropogon gerardii	15

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 27; Quadrat 1	% cover
Melilotus officinalis	70
Solidago missouriensis	40
Sorghastrum nutans	50
Panicum virgatum	50
Vernonia missurica	10

Plot 27; Quadrat 2	% cover
Melilotus officinalis	20
Sorghastrum nutans	90
Panicum virgatum	15

Plot 27; Quadrat 3	% cover
Sorghastrum nutans	10
Melilotus officinalis	70
Solidago missouriensis	70
Panicum virgatum	15

Plot 27; Quadrat 4	% cover
Solidago missouriensis	70
Sorghastrum nutans	15
Panicum virgatum	15

Plot 27; Quadrat 5	% cover
Glandularia bipinnitifida	5
Melilotus officinalis	80
Solidago missouriensis	80
Symphoricarpos orbiculatu	5

Plot 28; Quadrat 1	% cover
Solidago missouriensis	10
Melilotus officinalis	90
Panicum virgatum	60

Plot 28; Quadrat 2	% cover
Panicum virgatum	30
Melilotus officinalis	80
Solidago missouriensis	5
Sorghastrum nutans	50

Plot 28; Quadrat 3	% cover
Melilotus officinalis	10
Solidago missouriensis	30
Sorghastrum nutans	30
Panicum virgatum	30
Glandularia bipinnitifida	5

Plot 28; Quadrat 4	% cover
Andropogon gerardii	30
Melilotus officinalis	90
Solidago missouriensis	30
Sorghastrum nutans	30

Plot 28; Quadrat 5	% cover
Bouteloua dactyloides	80
Melilotus officinalis	10
Solidago missouriensis	10
Sorghastrum nutans	30

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 29; Quadrat 1	% cover
Solidago missouriensis	40
Melilotus officinalis	80
Eupatorium altissimum	20

Plot 29; Quadrat 2	% cover
Solidago missouriensis	60
Melilotus officinalis	90
Sorghastrum nutans	10
Panicum virgatum	20

Plot 29; Quadrat 3	% cover
Solidago missouriensis	40
Melilotus officinalis	80
Eupatorium altissimum	20

Plot 29; Quadrat 4	% cover
Rubus occidentalis	30
Passiflora incarnata L.	60

Plot 29; Quadrat 5	% cover
Solidago missouriensis	60
Melilotus officinalis	90
Andropogon gerardii	15

Plot 30; Quadrat 1	% cover
Solidago missouriensis	5
Melilotus officinalis	90
Andropogon gerardii	30
Panicum virgatum	40

Plot 30; Quadrat 2	% cover
Melilotus officinalis	15
Solidago missouriensis	30
Sorghastrum nutans	70
Panicum virgatum	50
Rhus copallina	10

Plot 30; Quadrat 3	% cover
Sorghastrum nutans	5
Melilotus officinalis	90
Glandularia bipinnitifida	1
Panicum virgatum	40

Plot 30; Quadrat 4	% cover
Sorghastrum nutans	10
Melilotus officinalis	90
Solidago missouriensis	5
Panicum virgatum	5

Plot 30; Quadrat 5	% cover
Rhus glabra	100
Rubus occidentalis	10

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 31; Quadrat 1	% cover
Solidago missouriensis	10
Melilotus officinalis	100
Eupatorium altissimum	5
Panicum virgatum	10

Plot 31; Quadrat 2	% cover
Solidago missouriensis	5
Melilotus officinalis	90
Sorghastrum nutans	5
Panicum virgatum	70

Plot 31; Quadrat 3	% cover
Solidago missouriensis	15
Melilotus officinalis	5
Sorghastrum nutans	30
Panicum virgatum	60

Plot 31; Quadrat 4	% cover
Melilotus officinalis	70
Panicum virgatum	70
Solidago missouriensis	10

Plot 31; Quadrat 5	% cover
Solidago missouriensis	20
Melilotus officinalis	90
Sorghastrum nutans	5
Panicum virgatum	10

Plot 32; Quadrat 1	% cover
Solidago missouriensis	10
Melilotus officinalis	90
Panicum virgatum	60

Plot 32; Quadrat 2	% cover
Schyzachyrium scoparium	30
Melilotus officinalis	75
Solidago missouriensis	60
Sorghastrum nutans	15

Plot 32; Quadrat 3	% cover
Panicum virgatum	5
Melilotus officinalis	80
Solidago missouriensis	80
Eupatorium altissimum	15

Plot 32; Quadrat 4	% cover
Panicum virgatum	10
Melilotus officinalis	90
Solidago missouriensis	15
Eupatorium altissimum	15

Plot 32; Quadrat 5	% cover
Panicum virgatum	5
Melilotus officinalis	50
Solidago missouriensis	25
Sorghastrum nutans	10

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 33; Quadrat 1	% cover
Panicum virgatum	20
Melilotus officinalis	10
Solidago missouriensis	40
Symphoricarpos orbiculatus	30

Plot 33; Quadrat 2	% cover
Panicum virgatum	50
Melilotus officinalis	10
Solidago missouriensis	80
Sorghastrum nutans	30

Plot 33; Quadrat 3	% cover
Panicum virgatum	20
Melilotus officinalis	75
Solidago missouriensis	70
Sorghastrum nutans	5

Plot 33; Quadrat 4	% cover
Solidago missouriensis	60
Melilotus officinalis	50
Panicum virgatum	20

Plot 33; Quadrat 5	% cover
Solidago missouriensis	20
Sorghastrum nutans	20
Melilotus officinalis	70
Panicum virgatum	15
Schyzachyrium scoparium	5

Plot 34; Quadrat 1	% cover
Panicum virgatum	80
Melilotus officinalis	5
Solidago missouriensis	40
Sorghastrum nutans	10

Plot 34; Quadrat 2	% cover
Panicum virgatum	80
Melilotus officinalis	5
Solidago missouriensis	40
Sorghastrum nutans	10

Plot 34; Quadrat 3	% cover
Solidago missouriensis	70
Melilotus officinalis	5
Panicum virgatum	70

Plot 34; Quadrat 4	% cover
Panicum virgatum	60
Melilotus officinalis	1
Solidago missouriensis	30
Sorghastrum nutans	30

Plot 34; Quadrat 5	% cover
Rubus flagellaris	10
Melilotus officinalis	70
Solidago missouriensis	30
Sorghastrum nutans	70

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 35; Quadrat 1	% cover
Solidago missouriensis	30
Melilotus officinalis	20
Sorghastrum nutans	90

Plot 35; Quadrat 2	% cover
Solidago missouriensis	15
Melilotus officinalis	90
Sorghastrum nutans	40

Plot 35; Quadrat 3	% cover
Panicum virgatum	15
Melilotus officinalis	60
Solidago missouriensis	90
Sorghastrum nutans	15

Plot 35; Quadrat 4	% cover
Solidago missouriensis	90
Panicum virgatum	5
Sorghastrum nutans	5

Plot 35; Quadrat 5	% cover
Solidago missouriensis	5
Melilotus officinalis	10
Sorghastrum nutans	100

Plot 36; Quadrat 1	% cover
Panicum virgatum	1
Melilotus officinalis	90
Solidago missouriensis	20
Sorghastrum nutans	15

Plot 36; Quadrat 2	% cover
Panicum virgatum	10
Melilotus officinalis	90
Solidago missouriensis	30
Sorghastrum nutans	20

Plot 36; Quadrat 3	% cover
Panicum virgatum	10
Melilotus officinalis	100
Solidago missouriensis	50
Sorghastrum nutans	10

Plot 36; Quadrat 4	% cover
Solidago missouriensis	10
Melilotus officinalis	70
Sorghastrum nutans	70

Plot 36; Quadrat 5	% cover
Melilotus officinalis	80
Andropogon gerardii	5
Sorghastrum nutans	10
Solidago missouriensis	30
Panicum virgatum	10
Eupatorium altissimum	5

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 37; Quadrat 1	% cover
Panicum virgatum	10
Melilotus officinalis	90
Sorghastrum nutans	70

Plot 37; Quadrat 2	% cover
Panicum virgatum	30
Melilotus officinalis	70
Solidago missouriensis	30
Sorghastrum nutans	50

Plot 37; Quadrat 3	% cover
Panicum virgatum	70
Melilotus officinalis	90
Solidago missouriensis	10
Sorghastrum nutans	15

Plot 37; Quadrat 4	% cover
Sorghastrum nutans	60
Melilotus officinalis	90

Plot 37; Quadrat 5	% cover
Panicum virgatum	15
Melilotus officinalis	90
Solidago missouriensis	15

Plot 38; Quadrat 1	% cover
Solidago missouriensis	10
Sorghastrum nutans	10
Melilotus officinalis	90
Panicum virgatum	10
Andropogon gerardii	5

Plot 38; Quadrat 2	% cover
Panicum virgatum	90
Melilotus officinalis	90
Rubus occidentalis	10

Plot 38; Quadrat 3	% cover
Solidago sp.	100

Plot 38; Quadrat 4	% cover
Solidago sp.	100

Plot 38; Quadrat 5	% cover
Solidago sp.	100
Populus deltoides	50

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 39; Quadrat 1	% cover
Panicum virgatum	15
Melilotus officinalis	90
Solidago missouriensis	40
Eupatorium altissimum	5

Plot 39; Quadrat 4	% cover
Panicum virgatum	15
Melilotus officinalis	90
Solidago missouriensis	40
Eupatorium altissimum	15

Plot 39; Quadrat 2	% cover
Solidago missouriensis	40
Melilotus officinalis	20
Panicum virgatum	15

Plot 39; Quadrat 5	% cover
Solidago missouriensis	90
Melilotus officinalis	70

Plot 39; Quadrat 3	% cover
Panicum virgatum	10
Melilotus officinalis	40
Solidago missouriensis	80
Eupatorium altissimum	5

Plot 40; Quadrat 1	% cover
Panicum virgatum	40
Melilotus officinalis	50
Solidago missouriensis	15
Sorghastrum nutans	15

Plot 40; Quadrat 4	% cover
Panicum virgatum	10
Schyzarynchium scoparium	30
Solidago missouriensis	5
Sorghastrum nutans	50

Plot 40; Quadrat 2	% cover
Solidago missouriensis	30
Panicum virgatum	15
Sorghastrum nutans	5

Plot 40; Quadrat 5	% cover
Solidago missouriensis	10
Panicum virgatum	100
Rubus Flagellaris	10

Plot 40; Quadrat 3	% cover
Solidago missouriensis	30
Panicum virgatum	70
Glandularia bipinnitifida	5

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 41; Quadrat 1	% cover
Solidago missouriensis	60
Sorghastrum nutans	15
Melilotus officinalis	70
Panicum virgatum	10
Andropogon gerardii	5

Plot 41; Quadrat 2	% cover
Solidago missouriensis	80
Panicum virgatum	15
Melilotus officinalis	7

Plot 41; Quadrat 3	% cover
Solidago missouriensis	70
Eupatorium altissimum	5
Melilotus officinalis	90

Plot 41; Quadrat 4	% cover
Panicum virgatum	35
Melilotus officinalis	90
Solidago missouriensis	10
Sorghastrum nutans	40

Plot 41; Quadrat 5	% cover
Solidago missouriensis	5
Panicum virgatum	60
Sorghastrum nutans	30

Plot 42; Quadrat 1	% cover
Solidago missouriensis	100
Melilotus officinalis	20
Panicum virgatum	15

Plot 42; Quadrat 2	% cover
Panicum virgatum	30
Melilotus officinalis	10
Solidago missouriensis	5
Sorghastrum nutans	70

Plot 42; Quadrat 3	% cover
Panicum virgatum	70
Melilotus officinalis	75
Solidago missouriensis	40
Pycnanthemum tenuifolium	5

Plot 42; Quadrat 4	% cover
Solidago missouriensis	80
Sorghastrum nutans	1
Melilotus officinalis	70
Panicum virgatum	20
Andropogon gerardii	15

Plot 42; Quadrat 5	% cover
Solidago missouriensis	5
Sorghastrum nutans	40
Melilotus officinalis	90
Panicum virgatum	70
Eupatorium altissimum	1

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 43; Quadrat 1	% cover
Solidago missouriensis	20
Melilotus officinalis	90
Panicum virgatum	35

Plot 43; Quadrat 4	% cover
Solidago missouriensis	60
Melilotus officinalis	80
Andropogon gerardii	3

Plot 43; Quadrat 2	% cover
Solidago missouriensis	60
Melilotus officinalis	60
Sorghastrum nutans	50

Plot 43; Quadrat 5	% cover
Solidago missouriensis	60
Melilotus officinalis	60
Sorghastrum nuatns	80

Plot 43; Quadrat 3	% cover
Panicum virgatum	20
Melilotus officinalis	90
Solidago missouriensis	15
Andropogon gerardii	40

Plot 44; Quadrat 1	% cover
Andropogon gerardii	40
Melilotus officinalis	90
Solidago missouriensis	40
Sorghastrum nutans	15

Plot 44; Quadrat 4	% cover
Sorghastrum nutans	20
Melilotus officinalis	95
Panicum virgatum	5

Plot 44; Quadrat 5	% cover
Sorghastrum nutans	70
Melilotus officinalis	70
Solidago missouriensis	20

Plot 44; Quadrat 2	% cover
Sorghastrum nutans	15
Symphocarpos orbiculatus	90

Plot 44; Quadrat 3	% cover
Melilotus officinalis	80
Andropogon gerardii	5
Sorghastrum nutans	10
Solidago missouriensis	30
Panicum virgatum	10

APPENDIX C (cont.) - Raw data by plot and quadrat

Plot 45; Quadrat 1	% cover
Panicum virgatum	100

Plot 45; Quadrat 2	% cover
Cornus dromundii	100
Symphoricarpos orbiculatu	50

Plot 45; Quadrat 3	% cover
Panicum virgatum	100

Plot 45; Quadrat 4	% cover
Panicum virgatum	100

Plot 45; Quadrat 5	% cover
Panicum virgatum	100

APPENDIX D - Necessary code for computing Functional Diversity in R

```
#Enter species functional trait values
>AAAA = c(4,5,1) #Ambrosia artemisiifolia
>AAASA = c(4,3,0) #Ageratina altissima
>AAMM = c(4,3,1) #Achillea millefolium
>AAVA = c(4,5,1) #Acalypha virginica
>ANGI = c(6,4,0) #Andropogon gerardii
>PMSI = c(6,4,0) #Pascopyrum smithii
>SMSUM = c(3,5,0) #Symphyotrichum subulatum
>BACA = c(6,3,0) #Bouteloua curtipendula
>BADS = c(6,3,0) #Buchloe dactyloides
>CACS = c(4,5,1) #Conyza canadensis
>CMAM = c(4,3,3) #Cirsium altissimum
>CSAM = c(8,1,0) #Cornus amomum
>CSDI = c(9,1,0) #Cornus dromundii
>DACA = c(4,3,0) #Dalea candida
>DAPA = c(4,3,0) #Dalea purpurea
```

(continued on next page)

APPENDIX B - Necessary code for computing Functional Diversity in R

```
>DSIS = c(7,2,0) #Desmanthus illinoensis
>EACI = c(6,5,0) #Echinochloa crus-galli
>ESUA = c(8,1,5) #Elaeagnus umbellata
>EAGS = c(4,3,0) #Euthamia gymnospermoides
```

APPENDIX D - Necessary code for computing Functional Diversity in R

```
>EMSM = c(4,4,1) #Eupatorium serotinum
>ENSS = c(4,3,0) #Erigeron strigosus
>FAPS = c(6,3,0) #Festuca pratensis
>GABS = c(3,4,1) #Gaura biennis
>GMVM = c(3,4,1) #Geum vernum
>HSAS = c(4,5,1) #Helianthus annuus
>HSMI = c(4,4,1) #Helianthus maximiliani
>IAAA = c(4,5,1) #Iva annua
>MSOS = c(4,5,0) #Melilotus officinalis
>OAVA = c(4,4,1) #Oenothera villosa
>OSDI = c(5,4,0) #Oxalis dillenii
>PAIA = c(15,4,0) #Passiflora incarnata  L.
```

(continued on next page)

APPENDIX B - Necessary code for computing Functional Diversity in R

```
>PAPS = c(6,4,0) #Poa pratensis
>PMCE = c(6,5,1) #Panicum capillare
>PMTM = c(4,4,0) #Pycnanthemum tenuifolium
>PMVM = c(6,3,0) #Panicum virgatum
>PSDS = c(9,1,0) #Populus deltoides
>PSHA = c(3,4,1) #Physalis heteropylla
>PSLA = c(3,4,0) #Physalis longifolia
>RAPA = c(4,4,1) #Ratibida pinnata
```

APPENDIX D - Necessary code for computing Functional Diversity in R

```
>RSCA = c(9,1,0) #Rhus copallina
>RSFS = c(7,1,3) #Rubus flagellaris
>RSGA = c(9,1,0) #Rhus glabra
>RSOIS = c(8,2,3) #Rubus occidentalis
>RSOUS = c(8,2,3) #Rubus ostryifolius
>SAPA = c(6,4,1) #Setaria parviflora
>SMCE = c(4,4,2) #Solanum carolinense
>SMDM = c(5,4,2) #Solanum dimidiatum
```
(continued on next page)

APPENDIX B - Necessary code for computing Functional Diversity in R

```
>SMNS = c(6,4,0) #Sorghastrum nutans
>SMPM = c(4,4,1) #Symphyotrichum pilosum
>SMSM = c(6,3,0) #Schizachyrium scoparium
>SOCS = c(4,3,1) #Solidago canadensis
>SOSP = c(4,3,1) #Solidago sp.
>SSAA = c(6,3,0) #Sporobolus aspera
>SSOA = c(6,3,0) #sphenopholis obtusata
>SSOS = c(8,1,0) #Symphoricarpos orbiculatus
>TMDS = c(6,4,0) #Tripsacum dactyloides
#Functional trait weights
w = c(1,1,1)
```
(continued on next page)

```
#1987
#generate trait matrix for 1987 sample
> traitmtrx1987 =
matrix(c(AAAA,ANGI,BACA,CACS,DACA,DAPA,EACI,ESUA,HSAS,IAAA,MSOS,
PMSI,PMVM,PSDS,SAPA,SMNS,SMSM,SMSUM,SOSP), nrow=19, ncol=3, byrow =
TRUE)
> rownames(traitmtrx1987) =
c("AAAA","ANGI","BACA","CACS","DACA","DAPA","EACI","ESUA","HSAS","IA
AA","MSOS","PMSI","PMVM","PSDS","SAPA","SMNS","SMSM","SMSUM","SOSP
")
> colnames(traitmtrx1987) = c("grwthfrm", "lffrm", "spine")
#generate abundance matrix for 1987 sample
> abundmtrx1987 =
matrix(c(0.49,0.01,0.66,0.04,0.12,0.04,0.01,0.01,0.05,0.02,0.92,0.10,0.52,0.01,0.01,0.05,
0.05,0.36,0.83), nrow=1, ncol=19)
> colnames(abundmtrx1987) =
c("AAAA","ANGI","BACA","CACS","DACA","DAPA","EACI","ESUA","HSAS","IA
AA","MSOS","PMSI","PMVM","PSDS","SAPA","SMNS","SMSM","SMSUM","SOSP
")
> rownames(abundmtrx1987) = "Abundance"
#Calculate Functional Diversity
> FD1987 = dbFD(traitmtrx1987, abundmtrx1987, w, w.abun = TRUE, stand.x = TRUE,
ord = c("podani", "metric"), asym.bin = NULL, corr = c("sqrt", "cailliez", "lingoes",
"none"), calc.FRic = TRUE, m = "max", stand.FRic = FALSE, scale.RaoQ = FALSE,
calc.FGR = FALSE, clust.type = "ward", km.inf.gr = 2, km.sup.gr = nrow(x) - 1, km.iter
= 100, km.crit = c("calinski", "ssi"), calc.CWM = TRUE, CWM.type = c("dom", "all"),
calc.FDiv = TRUE, dist.bin = 2, print.pco = FALSE, messages = TRUE)
```

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```
#1988
#generate trait matrix for 1988 sample
> traitmtrx1988 =
matrix(c(AAAA,ANGI,BACA,BADS,DAPA,DSIS,EACI,HSAS,HSMI,IAAA,MSOS,P
MSI,PMVM,SAPA,SMCE,SMNS,SMSM,SMSUM,SOSP), nrow=19, ncol=3, byrow =
TRUE)
> rownames(traitmtrx1988) =
c("AAAA","ANGI","BACA","BADS","DAPA","DSIS","EACI","HSAS","HSMI","IAA
A","MSOS","PMSI","PMVM","SAPA","SMCE","SMNS","SMSM","SMSUM","SOSP"
)
>colnames(traitmtrx1988) = c("grwthfrm", "lffrm", "spine")
#generate abundance matrix for 1988 sample
abundmtrx1988 =
matrix(c(0.04,0.11,0.73,0.03,0.02,0.01,0.01,0.01,0.02,0.01,0.01,0.07,0.56,0.01,0.01,0.06,
0.10,0.01,0.05), nrow=1, ncol=19)
> colnames(abundmtrx1988) =
c("AAAA","ANGI","BACA","BADS","DAPA","DSIS","EACI","HSAS","HSMI","IAA
A","MSOS","PMSI","PMVM","SAPA","SMCE","SMNS","SMSM","SMSUM","SOSP"
)
> rownames(abundmtrx1988) = "Abundance"
#Calculate Functional Diversity
> FD1988 = dbFD(traitmtrx1988, abundmtrx1988, w, w.abun = TRUE, stand.x = TRUE,
ord = c("podani", "metric"), asym.bin = NULL, corr = c("sqrt", "cailliez", "lingoes",
"none"), calc.FRic = TRUE, m = "max", stand.FRic = FALSE, scale.RaoQ = FALSE,
calc.FGR = FALSE, clust.type = "ward", km.inf.gr = 2, km.sup.gr = nrow(x) - 1, km.iter
= 100, km.crit = c("calinski", "ssi"), calc.CWM = TRUE, CWM.type = c("dom", "all"),
calc.FDiv = TRUE, dist.bin = 2, print.pco = FALSE, messages = TRUE)
```

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```
#1994
#generate trait matrix for 1994 sample
> traitmtrx1994 =
matrix(c(AAASA,AAMM,AAVA,ANGI,BACA,BADS,CACS,CSDI,DAPA,DSIS,EAG
S,ENSS,FAPS,GABS,GMVM,HSMI,OSDI,PAPS,PMCE,PMSI,PMTM,PMVM,PSDS,P
SLA,RAPA,SMNS,SMPM,SMSM,SOCS,SSAA,SSOA,TMDS), nrow=32, ncol=3,
byrow = TRUE)
> rownames(traitmtrx1994) =
c("AAASA","AAMM","AAVA","ANGI","BACA","BADS","CACS","CSDI","DAPA","
DSIS","EAGS","ENSS","FAPS","GABS","GMVM","HSMI","OSDI","PAPS","PMCE",
"PMSI","PMTM","PMVM","PSDS","PSLA","RAPA","SMNS","SMPM","SMSM","SO
CS","SSAA","SSOA","TMDS")
> colnames(traitmtrx1994) = c("grwthfrm", "lffrm", "spine")
#generate abundance matrix for 1994
> abundmtrx1994 =
matrix(c(0.08,0.05,0.21,0.95,0.90,0.08,0.05,0.08,0.18,0.11,0.07,0.83,0.10,0.14,0.18,0.32,
0.09,0.26,0.09,0.09,0.69,1.00,0.05,0.08,0.08,0.74,0.27,0.76,0.97,0.21,0.21,0.06), nrow=1,
ncol=32)
> colnames(abundmtrx1994) =
c("AAASA","AAMM","AAVA","ANGI","BACA","BADS","CACS","CSDI","DAPA","
DSIS","EAGS","ENSS","FAPS","GABS","GMVM","HSMI","OSDI","PAPS","PMCE",
"PMSI","PMTM","PMVM","PSDS","PSLA","RAPA","SMNS","SMPM","SMSM","SO
CS","SSAA","SSOA","TMDS")
> rownames(abundmtrx1994) = "Abundance"
#calculate Functional Diversity
> FD1994 = dbFD(traitmtrx1994, abundmtrx1994, w, w.abun = TRUE, stand.x = TRUE,
ord = c("podani", "metric"), asym.bin = NULL, corr = c("sqrt", "cailliez", "lingoes",
"none"), calc.FRic = TRUE, m = "max", stand.FRic = FALSE, scale.RaoQ = FALSE,
calc.FGR = FALSE, clust.type = "ward", km.inf.gr = 2, km.sup.gr = nrow(x) - 1, km.iter
= 100, km.crit = c("calinski", "ssi"), calc.CWM = TRUE, CWM.type = c("dom", "all"),
calc.FDiv = TRUE, dist.bin = 2, print.pco = FALSE, messages = TRUE)
```

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APPENDIX D - Necessary code for computing Functional Diversity in R (cont.)

```
#2014
#generate trait matrix for 2014 sample
> traitmtrx2014 =
matrix(c(AAAA,ANGI,BACA,BADS,CACS,CMAM,CSAM,CSDI,DSIS,EMSM,HSMI,
MSOS,OAVA,PAIA,PMSI,PMTM,PMVM,PSDS,PSHA,RSCA,RSFS,RSGA,RSOIS,RS
OUS,SMDM,SMNS,SMSM,SOSP,SSOS),nrow=29, ncol=3, byrow = TRUE)
> rownames(traitmtrx2014) =
c("AAAA","ANGI","BACA","BADS","CACS","CMAM","CSAM","CSDI","DSIS","E
MSM","HSMI","MSOS","OAVA","PAIA","PMSI","PMTM","PMVM","PSDS","PSHA
","RSCA","RSFS","RSGA","RSOIS","RSOUS","SMDM","SMNS","SMSM","SOSP","S
SOS")
> colnames(traitmtrx2014) = c("grwthfrm", "lffrm", "spine")
#generate abundance matrix for 2014 sample
abundmtrx2014 =
matrix(c(0.08,0.15,0.08,0.06,0.05,0.004,0.04,0.04,0.01,0.14,0.04,0.77,0.05,0.004,0.01,0.0
8,0.74, 0.01,0.004,0.04,0.02,0.04,0.01,0.01,0.01,0.37,0.06,0.72,0.04), nrow=1, ncol=29)
> colnames(abundmtrx2014) =
c("AAAA","ANGI","BACA","BADS","CACS","CMAM","CSAM","CSDI","DSIS","E
MSM","HSMI","MSOS","OAVA","PAIA","PMSI","PMTM","PMVM","PSDS","PSHA
","RSCA","RSFS","RSGA","RSOIS","RSOUS","SMDM","SMNS","SMSM","SOSP","S
SOS")
> rownames(abundmtrx2014) = "Abundance"
#Calculate Functional Diversity
> FD2014 = dbFD(traitmtrx2014, abundmtrx2014, w, w.abun = TRUE, stand.x = TRUE,
ord = c("podani", "metric"), asym.bin = NULL, corr = c("sqrt", "cailliez", "lingoes",
"none"), calc.FRic = TRUE, m = "max", stand.FRic = FALSE, scale.RaoQ = FALSE,
calc.FGR = FALSE, clust.type = "ward", km.inf.gr = 2, km.sup.gr = nrow(x) - 1, km.iter
= 100, km.crit = c("calinski", "ssi"), calc.CWM = TRUE, CWM.type = c("dom", "all"),
calc.FDiv = TRUE, dist.bin = 2, print.pco = FALSE, messages = TRUE)
```