5-1-2012

Response of riparian areas of the shortgrass steppe to anthropogenic disturbance and assessment of students' changed understanding of ecosystem reclamation through experience

Michael Henry Schiebout
University of Northern Colorado

UNIVERSITY OF NORTHERN COLORADO

Greeley, Colorado

The Graduate School

RESPONSE OF RIPARIAN AREAS OF THE SHORTGRASS STEPPE TO ANTHROPOGENIC DISTURBANCE AND ASSESSMENT OF STUDENTS' CHANGED UNDERSTANDING OF ECOSYSTEM RECLAMATION THROUGH EXPERIENCE

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

Michael Henry Schiebout

College of Natural Health Sciences
School of Biological Sciences
Biological Education
May 2012

This Dissertation by: Michael Henry Schiebout

Entitled: Response of riparian areas of the shortgrass steppe to anthropogenic disturbance and assessment of students' changed understanding of ecosystem reclamation through experience

has been approved as meeting the requirement for the Degree of Doctor of Philosophy in College of Natural Health Sciences, in School of Biological Sciences, Program of Biological Education

Accepted by the Doctoral Committee

____

Scott Franklin, Ph.D., Chair

____

Mitchell McGlaughlin, Ph.D., Committee Member

____

Robert Reinsvold, Ph.D., Committee Member

____

William Hoyt, Ph.D., Faculty Representative

Date of Dissertation Defense: ________________________________

Accepted by the Graduate School

____

Linda L. Black, Ed.D., LPC
Acting Dean of the Graduate School and International Admissions

ABSTRACT

Schiebout, Michael Henry *Response of riparian areas of the shortgrass steppe to anthropogenic disturbance and assessment of students' changed understanding of ecosystem reclamation through experience*. Published Doctor of Philosophy dissertation, University of Northern Colorado, 2012.

Most vegetation communities are in some way impacted by humans. This dissertation is composed of a series of studies aimed at understanding how the shortgrass steppe in northeastern Colorado responds to human disturbance. Specifically, it addresses the impact of gravel mining on a riparian area of the shortgrass steppe and its response to reclamation efforts. In addition, the impact of cattle grazing on the shortgrass steppe was investigated using exclosures. Studies concerning competition of noxious weeds present at the reclamation site were also conducted, both in the field and greenhouse. Finally, a qualitative study was completed addressing how student understanding and perception of gravel mine reclamation changed after visiting a mine reclamation site.

The reclamation study evaluated plant and soil composition of an aggregate mine site on the shortgrass steppe of northeastern Colorado to determine its status five years following active mining. This assessment was made by comparing the gravel mine site to minimally-impacted reference sites on the Pawnee National Grasslands. Community composition, soil characteristics and productivity were all significantly different for the mined site. In particular, soil phosphorus and soil potassium levels were lower. In addition, the gravel mine site had lower levels of below-ground biomass. The results

indicate that reclamation efforts on the mined site have been successful in establishing ground cover composed of native grasses and establishing functionally similar species to the references sites. Planting more native forbs and adding phosphorus and potassium to the soil is recommended to bring the experimental site closer to the reference site conditions. Grazing effects on riparian areas of the shortgrass steppe were tested using a seasonal and a multi-year study. Species composition and functional composition were compared for areas exposed to grazing and areas released from grazing. Soil nutrient levels and biomass levels were also compared but only over one grazing season. Results from the single grazing season study showed areas exposed to grazing had less above-ground biomass and greater heterogeneity than non-grazed areas. The multi-year study showed that species composition differed between grazed and un-grazed areas from the onset but demonstrated similar dynamics for diversity and species composition. The data suggested other environmental factors, perhaps hail, had a greater impact on the system than grazing. Release from grazing caused the system to change more than continual grazing and resulted in increased species evenness. This study demonstrated variability of species composition from year to year on the shortgrass steppe and supported the concept that grazing has minimal impact in regions adapted to low levels of precipitation. The competition studies investigated the possibility of utilizing native functionally equivalent plants as a means to control the spread and dominance of noxious weeds. Greenhouse and field studies were conducted to investigate the impact plant functionality and nativeness have on competitive ability of the ubiquitous noxious species *Bromus tectorum* and *Cirsium arvense*. Results indicate that *Vulpia octoflora* may inhibit the growth of *Bromus tectorum* but has little impact on *Cirsium arvense*, and that *Achillea*

millifolium var. *lanulosa* does not significantly impact the growth of these noxious weeds. In the field, increased graminoid cover predicted decreased performance of *Cirsium arvense*. Data support the current practice of planting native perennial grasses in reclamation sites is an effective control measure for containing *Cirsium arvense* on the shortgrass steppe and suggest that planting *Vulpia octoflora* may be useful in controlling *Bromus tectorum*. A case study utilizing interviews, drawings, and observations was conducted. The goal of this case study was to investigate understanding and perceptions of high school geology students toward aggregate mining prior to and after a visit to a gravel mine reclamation site. Five underlying themes emerged from the data: increased knowledge of the gravel mining and reclamation processes, vocalization of the importance of reclamation, increased understanding of the structural composition of a gravel mine reclamation site on the shortgrass steppe, decreased emphasis of an anthropocentric purpose of mine reclamation, and identification of the location of a specific reclamation site. These results elucidate the importance in place-based education for developing student understanding of science concepts and stewardship perspectives.

ACKNOWLEDGEMENTS

No one starts on an endeavor such as a Ph.D. and sees it to completion without the guidance, encouragement and support of a great team of individuals.

I am grateful for Scott Franklin for accepting me as a Doctoral student. I appreciate the many hours of work both in the field, greenhouse and in mentoring me through the design and writing process. Many stories can be told of these experiences. He was always helpful, cheerful, and willing to answer any of my questions. I am also thankful for the other members of my committee; Rob Reinsvold, Mitt McGlaughlin and Bill Hoyt. Each of these individuals made significant ($p<0.0001$) contributions to the quality of my dissertation.

I would like to thank the many other faculty members at UNC who through this process were willing to give their time and effort in mentoring me. These individual include my Master's advisor Neil Snow and cell and molecular biology mentors Susan Keenan and Patrick Burns. Both persevered with me as I worked to gain knowledge, training and understanding in the field of molecular biology.

Thanks goes out to the Poudre Learning Center staff and in particular to the director, Ray Tschillard, who enabled me to conduct research at the PLC. He is also a good friend who made the work at the PLC enjoyable with tasks including movement of road base by hand, putting in the dock, and hand planting the very first shrubs now composing the wind break.

Don Hazlett deserves much credit for my training as a field biologist. I am thankful for his friendship, advice, botanical experience and of course the many lunches. I have enjoyed every field endeavor we have done together, starting with the collecting in Mills Canyon and continuing with the work on Eagle Rock Ranch.

I would like to thank Mary Ashby for allowing me to conduct research on the CPER and for always being willing to help with supplies such as exclosure cages and questions. I thank Judy Firestein for her permission to conduct research on her property and for always having a cheerful attitude.

I am grateful for Gary Frasier who allowed me to work with data that was initially collected under his supervision and also Mary Ann Murphy for her willingness to help out whenever I asked.

I am thankful for help in the field and lab from a number of teachers, graduate students, and undergraduate students including: Robert Frederick, Amber Brant, Morgan Hockley, and Isaiah Runyan.

I am very appreciative for the support my wife Jodi has given me - for always believing in me and finding ways to enjoy the journey with me through this process. She is the best partner anyone could ask for. I would like to thank my children; Allison, Monique, Henry, and Grant. For three of them, this life is the only one they have known and I appreciate their love. I would like to thank my extended family as well. In particular, I am thankful for my sister Valerie and my in-laws who were willing to provide childcare at times. Both sets of our parents have been great encouragers and have come along side us in many tangible, generous and supportive ways.

I would like to acknowledge the funding I have received to conduct my research and to support my graduate education; the Flood and Peterson scholarship, the GAANN Fellowship, NSF GK-12 Fellowship, NSF-MSP Grant, the Robert Sund Scholarship, the School of Biological Sciences and the Winchester Graduate Fellowship.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION AND OVERVIEW

The shortgrass steppe region of northeastern Colorado has been impacted by human and naturally-caused disturbances. Some of the disturbances impacting this region are intense such as mining and construction. Others are more subtle such as drought, grazing and the impact of prairie dogs (Peters et al., 2008). These more consistent disturbances have shaped the vegetation patterns observed on the shortgrass steppe. As humans continue to encroach on natural areas, it is important to understand how systems respond to this pressure and equally important to understand how citizens view these disturbances. Without community support, conservation and stewardship activities are constrained. One of the goals of environmental education is to develop in students an understanding of the natural world, the impact humans have on the natural world, and the processes such as land reclamation and restoration that mitigate human impacts (Davis, 1998; Thomson & Hoffman, 2004). Through ecological and environmental science education utilizing experiences with nature, students gain an eco-consciousness and desire to minimally impact the natural world (Knapp, 1999). To make a successful transition toward eco-consciousness, students must understand human impacts on the natural world and perceive the need for intervening through the process of restoration and reclamation. This dissertation investigated the response of the shortgrass steppe to gravel mine reclamation and release from cattle grazing as well as high school students' changed perceptions after visiting a gravel mine reclamation site. Included in the dissertation is a study which investigated noxious weed interactions with native vegetation in an attempt to understand mechanistic controls of community assemblage that may be used for restoration.

The following introduces the main purpose and research topics of the dissertation, beginning with the need for assessing restoration of the shortgrass steppe. Brief introductions to disturbance theory, invasion biology, and ecological education (major drivers of restoration success) give the background information to understand the studies in the following chapters. This chapter concludes with specific characteristics of the study sites and description of remaining chapters.

Need for Restoration of the Shortgrass Steppe

Without restoration, damage caused to ecosystems by extreme disturbances will not recover in a timely manner (Bradshaw, 2002). Reclamation mitigates the negative impacts on environments (Ng, 2002). Although the process of restoration does not create an ecosystem identical to that previous to perturbation, successful restoration should develop a community with similar function as the pre-disturbed environment (Choi, 2007).

Evaluation of reclamation success for grasslands is needed. Many previous studies evaluating restoration success dealt with other ecosystems (Ruiz-Jaen & Aide, 2005), but data in arid grasslands are lacking. Assessing restoration success in arid grasslands is needed.

Current reclamation evaluation of mined sites in Colorado requires a determination of sustainable ground cover of a reclamation site composed of desirable plant species (Assembly, 2008). These parameters are important, but they do not require an assessment of community function or compare a reclaimed site to an intact functional reference ecosystem. One of my studies did that and can now serve as a template for determining the level of restoration success in other regions.

Description of the Shortgrass Steppe

The shortgrass steppe is a unique ecosystem characterized by low precipitation; average annual precipitation levels of 260-375 mm (Anderson, 2006; Pielke & Doesken, 2008). Because of the low levels of precipitation, this community responds differently to disturbances (Stapp et al., 2008) and contributes to an ecosystem dominated by perennial warm season grass. The dominant grasses found include blue grama (*Bouteloua gracilis*) and buffalo grass (*Bouteloua dactyloides*) (Lauenroth, 2008). Periodic droughts contribute to the lack of shrubs in the region; the shrubs that are found are adapted to low precipitation levels and include saltbush (*Atriplex canesens*), rabbit bush (*Chrysothamnus nauseosus*), plains prickly pear cactus (*Opuntia polyanthemos*), and soapweed yucca (*Yucca glauca*).

Low levels of precipitation prevent large rivers from dominating the region, but smaller creeks and ephemeral stream beds (Singh et al., 1996) are common. The studies included in this dissertation specifically focused on these lowland areas. Riparian areas on the shortgrass steppe provide unique habitat for many native and exotic plants and are utilized for forage more frequently than upland areas by cattle (Lauenroth & Milchunas, 1991b). One novelty of this dissertation is the focus of disturbance effects on these less-studied riparian communities.

Disturbance and the Community

For this dissertation, a disturbance will be defined as an event in time and place that alters the structure of populations, communities, and ecosystems. The structural changes modify resource availability of the physical environment (White & Pickett, 1985). Disturbances could be a chronic long term event such as cattle grazing or climate change –or a more immediate event such as drought, mining, oil drilling or fire. Disturbances frequently precipitate a cascade effect elevating the impact of other stresses in the environment (Sousa, 1984).

Change in community structure is a key effect of a disturbance. Vegetation present prior to the disturbance will be changed and the level of change is contingent on the magnitude and severity of the disturbance. This structural change will contribute to changes in resource and substrate availability.

Disturbances interact with the landscape. The location, structure, elevation, and species composition of the landscape all determine the impact a disturbance will have on an ecosystem. In addition, the disturbance often dictates the type of plants capable of living in an area, either by the selective stress of the disturbance or the post-disturbance environment (Grime, 1977). Mining may elicit particularly strong stressors and filters. Resources that were used by one plant destroyed by mining become available for other plants. Plants able to gain a hold quickly, utilize the available resources, and reproduce abundantly dominate (Denslow, 1980). For aggregate mining, not only have the existing native plants been removed, but the seed bank may also have been removed opening up the site to species that have long distance dispersal methods and thrive in dry conditions on the shortgrass steppe.

A novel disturbance such as gravel mining will have a greater impact on the shortgrass steppe verses a long-term chronic disturbance because the system likely has not adapted to the novel experience. For example, much of the overburden used in surface mine reclamation is deficient in both nitrogen and phosphorus (Sengupta, 1993). Sunlight availability also increases in mined areas previously occupied by standing vegetation, and increased light availability contributes to the increase in invasive weeds following disturbance (Tilman, 1986).

An example of a long term chronic disturbance is grazing. Ungulate grazing has had and continues to have a profound influence on plant structure of the shortgrass steppe (Milchunas et al., 1988b). Because cattle spend more time during the summer months in lowland/riparian areas of the shortgrass steppe, these areas are grazed more frequently than corresponding upland areas (Lauenroth & Milchunas, 1991b). This increased grazing pressure increases the negative impacts of heavy grazing. In addition, grazed riparian areas are more susceptible to trampling and elimination of vegetation (Clary & Webster, 1989). From the results of this dissertation, resource managers will be better able to make land use decisions with knowledge of how riparian areas of the shortgrass steppe respond to reduced grazing or cessation of grazing.

Hypotheses for Invasive Plant Success

A number of hypotheses have been postulated to predict invasiveness of a species into a community and the invasibility of the community itself. The hypotheses predict invasion based on: similarity to native species, species intrinsic evolution rate, ability to utilize resources not currently being utilized in a community, possession of novel traits with which to interact with the environment, adaption to disturbance, species richness of the invaded community, and level of propagule pressure (Hierro et al., 2005).

Darwin's naturalization hypothesis predicts that similar taxa (taxonomically or functionally) are prevented from invading because they encounter similar functional competitors (Wolfe, 2002; Thuiller et al., 2010). Therefore exotics that are different are more likely to successfully invade communities (Diez et al., 2008). These unique species can utilize resources not being used in an ecosystem and will fill a void not occupied by current vegetation (Elton, 1958; Macarthur, 1972; Tilman, 1997). For example, a species that has deeper roots than the native vegetation would have an advantage in sequestering water and would have the ability to grow without direct competition for the resource.

With an increased intrinsic evolutionary rate, an invasive species will be successful if the species has the ability to change rapidly in a new environment. This ability to rapidly change is an adaptive trait which enables the species to take advantage of available resources and resist predators (Lee, 2002; Stockwell et al., 2003).

Some species have novel traits that enable them to inhibit the growth of natives. These novel traits often include allopathic chemicals, which may have coevolved in the original environment to confer resistance against plants and predators (Thorpe et al., 2009). In the invaded community, little resistance has been built up by native plants or predators (Callaway & Aschehoug, 2000; Thorpe et al., 2009; Wilsey et al., 2009).

Plants adapted to disturbance will successfully invade disturbed environments (Gray, 1879; Burke & Grime, 1996; Yurkonis et al., 2012). These plants will likely be r-strategists able to respond quickly to disturbance and typically have short lives, rapid development, many offspring and excellent dispersal ability. Some of these colonizers need disturbance to exist because of their poor competition ability (Sousa, 1984). As such, invasive species that need disturbances to thrive should not dominate a community moving toward stability.

Increased species richness is predicted to prevent species invasion because more of the available space and resources are being allocated to the current species. Communities with low levels of diversity will afford opportunities for invaders (Elton, 1958; Tilman, 1997; Kreyling et al., 2008).

Some ecologists have proposed that invasive success is due primarily to propagule pressure (Williamson & Fitter, 1996; Lonsdale, 1999; Kolar & Lodge, 2001; Eschtruth & Battles, 2009). If a large number of seeds are continually brought into a community, it is likely they will invade, assuming they have the genetic plasticity to grow and reproduce in the new environment.

Linking the Science to Education

Mining, construction and agriculture are important and needed components of our society and yet they negatively impact the natural world. This impact is seen through removed topsoil, chemical leaching, soil erosion, and loss of habitat (Sengupta, 1993). As urbanization continues to encroach and degrade intact, self supporting, and resilient land, more areas will be in need of and benefit from restoration and reclamation. Yet many people do not have an understanding of the reclamation process or its importance, nor do we know its efficacy. As part of this project, a study was developed to specifically investigate students' perception of an aggregate mined site after visiting a reclamation site. Individuals generally are unsure of or have negative ideas about the impact of mining on natural environments (Bloodworth et al., 2009). They have even less understanding of the importance and process of reclamation and how an environment changes through the reclamation process. Gaining an understanding of students' perceptions will allow teachers in the future to develop methods that more effectively communicate how reclamation benefits a disturbed environment. In addition, students themselves will apply direct experiences to develop an understanding of the importance of reclamation in their communities. This information can then be applied as students make future ecological decisions (NAAEE, 2004).

This study aimed to investigate student understanding of the impacts and mitigation involved in gravel mining and was the first study describing how students' perceptions change in response to a direct experience with an aggregate mine reclamation site. Although students have a general idea of how human impacts affect a natural site (Yow, 2008), they do not have clear understanding about specific processes. One way to change these misconceptions is through experiential activities that modify an individual's perspective and understanding (Dewey, 1938; NAAEE, 2004). These types of experiences can also give students a sense of place and an appreciation for nature (Louv, 2005) which enhances their knowledge of natural processes.

As environmental educators work to help their students develop an understanding of the natural world, there is also a hope that students will gain a desire to positively impact the natural world. To make successful transitions toward eco-consciousness, students must understand destructive human impact on the natural world and perceive the need for intervening through the process of restoration and reclamation to improve the condition of an impacted area. It is expected that direct experience will enhance their understanding and heighten their perception of the importance of these intervention processes.

Characteristics of the Research Sites

Two locations on the shortgrass steppe in northeastern Colorado were used for this research. These locations were the Poudre Learning Center (PLC) including a contiguous area north of the center and the Shortgrass Steppe Long-Term Ecological Research Site (SGS LTER) located on the Pawnee National Grasslands.

The PLC located in Weld County, Colorado along the Cache la Poudre River (40°26'35" N latitude, 104 °48'55" W longitude) with an average elevation of 1437 meters. The site was actively mined for sand and gravel from 1986-2003. Prior to mining, this area showed a heterogeneous landscape consisting of 26.3 hectares of shortgrass steppe, wetland, and riparian/terrace habitat (Resh & Chimmer, 2005). The influence of the Poudre River has provided some complexity to the site, allowing patches of taller grasses to occur in the year-round moister conditions of the associated riparian areas. As is the case with many degraded landscapes, the PLC has more noxious invasive weeds than undisturbed landscapes.

Active gravel mining was terminated on the site in 2003 and the removal of overburden was completed in 2006. An augmented lake was created on the site and the topography was returned to a state similar to that of pre-mining. In 2006, the site was tilled and seeded with a native grass seed mix. The seeds were covered with weed-free straw mulch to prevent soil erosion and maintain soil moisture. No native forbs were included in the replanting efforts. The site has also been managed to control the invasion of noxious weeds through a combination of methods such as manual removal, localized herbicide use, and mowing. In addition, bindweed mite has been utilized in areas as a biological control against *Convolvulus arvensis*.

The PLC is also impacted by disturbances other than mining. Prior to gravel mining the area had been utilized for agriculture and adjacent land areas are still being utilized for grazing and crop farming. In addition, by being located adjacent to the Cache la Poudre River the center has been impacted directly by flooding. The more periodic flooding can be seen on the sand bars and dirt bars located along the river. More extreme flooding has occurred in the site as well and water has covered most of the site at times within the last 30 years. Flooding also affects the plants located at the site, in particular the plains cottonwoods, the sand bar willows, and the peach leaf willows found along the Poudre river corridor. This flooding and movement of the river over time has also contributed to soil diversity on the site.

The other research area was located at the Shortgrass Steppe Long-Term Ecological Research (SGS LTER) located approximately 40 km north of Greeley, Colorado. The SGS LTER is composed of the USDA ARS Central Plains Experimental Range (CPER) forming the western boundary and is part of the larger USDA Forest Service Pawnee National Grassland (PNG) extending east of the site (Lauenroth et al., 2008). The CPER is a continuous 6280 ha block of land (40°49' N latitude, 104 °47" W longitude) and was established by purchasing the land from farmers and ranchers unable to keep their land following the dust storms and drought of the 1930’s. Cattle grazing has occurred on the CPER since 1939 (Lauenroth & Milchunas, 1991a). The Pawnee

National Grassland is composed of 78,100 ha of public land that lies within a patchwork of private land. Average yearly precipitation for this site is 321 mm (Lauenroth et al., 2008).

Summary of Dissertation

The first aim of this dissertation, Chapter II, was to assess the response of the shortgrass steppe to gravel mining after five years of active reclamation. Determining reclamation success is imperative to evaluate current reclamation practices. This study evaluated the plant and soil reclamation of an aggregate mine site at the PLC by comparing the gravel mine site to minimally impacted reference sites on the shortgrass steppe. Community composition, soil characteristics and productivity were measured and compared.

The second aim, Chapter III, was to investigate the response of riparian/lowland areas of the shortgrass steppe to release from cattle grazing using exclosures. Human impact on grassland areas through cattle grazing has had a profound influence on plant structure and composition in these areas. The investigation was conducted at two different spatial and temporal scales. Specifically, one study was conducted over one grazing season utilizing 1 m^2 plots and the other was conducted over a five year period utilizing twelve 50 meter transects. Species composition and functional composition were compared for areas exposed to grazing and areas released from grazing. In addition, soil nutrient levels and biomass levels were compared over one grazing season.

The third aim, Chapter IV, was an assessment of competition between noxious weeds and functionally equivalent natives utilizing field and greenhouse studies. A goal of restoration is to develop an ecosystem which is functioning similar to the one prior to the disturbance event. Studies investigated the possibility of utilizing native functionally equivalent plants as a means to control the spread and dominance of noxious weeds. Greenhouse and field studies were conducted to investigate the impact that plant functionality and nativeness have on competitive ability of the ubiquitous noxious species *Bromus tectorum* and *Cirsium arvense*. In the greenhouse, these species were grown with each other and with the native species *Vulpia octoflora* and *Achillea millifolium* var. *lanulosa*. Growth parameters including height, number of leaves and above and belowground biomass were recorded and compared. In the field, growth of *Cirsium arvense* was investigated with ground cover vegetation (competiton) and without ground cover vegetation to determine the effect ground cover composition has on growth and fecundity of the species.

The fourth and final aim, Chapter V, was to assess changes in perception and understanding of high school students toward a gravel mine reclamation site. One of the goals of environmental education is to develop in students an understanding of the natural world and through this learning process to develop in students an eco-consciousness. This perspective translates into a desire to impact the natural world in a positive way. The study was a qualitative case study that investigated understanding and perceptions of high school geology students toward aggregate mining prior to and after a visit to a gravel mine reclamation site through interviews, drawings, and observations.

CHAPTER II

SHORTGRASS STEPPE RESPONSE TO GRAVEL MINING WITH ACTIVE RECLAMATION INTERVENTION

Abstract

Reclamation is needed to restore areas damaged by human activities to a level of ecological sustainability and functional diversity. Determining reclamation success is imperative to evaluate current reclamation practices. This study evaluated the plant and soil reclamation of an aggregate mine site on the shortgrass steppe of northeastern Colorado to determine its status five years after mining activity was terminated. This assessment was made by comparing the gravel mine site to minimally impacted reference sites on the shortgrass steppe. Community composition, soil characteristics and productivity were all significantly different for the research site. In particular, soil phosphorus and soil potassium levels were lower for the mined site. In addition, the gravel mine site had lower levels of belowground biomass. The results of this study indicate that reclamation efforts on the gravel mine site have been successful in establishing ground cover composed of native grasses and establishing functionally similar species to the references sites. Planting more native forbs and adding phosphorus and potassium to the soil is recommended to bring the experimental site closer to the reference site conditions.

Introduction

Restoration is a practical means of mitigating the impact humans have had on many natural environments. The shortgrass steppe region of Colorado is no exception, although some of the disturbances impacting this region are more destructive than others; e.g., mining and construction. Others are more subtle, such as drought, cattle grazing and the impact of prairie dogs (Peters et al., 2008). The more consistent disturbances have shaped the vegetation patterns observed on the shorgrass steppe. Grasslands in general lack studies to assess restoration success (Ruiz-Jaen & Aide, 2005), and, considering the unique structural composition and climate variables of the shortgrass steppe (Munson & Lauenroth, 2011), assessment of restoration projects of degraded areas is especially needed. The aim of this study was to assess the status of a gravel mine reclamation site on the shortgrass steppe five years after mining was terminated by comparing it to two intact reference sites. Comparisons included community composition, soil characteristics, and productivity.

The shortgrass steppe is a unique ecosystem characterized by low levels of precipitation (260-375 mm; (Anderson, 2006)) and large and rapid temperature changes (Pielke & Doesken, 2008). The shortgrass steppe is impacted by the low level of precipitation in general and periodic drought more directly. This semiarid environment is unique compared to other grasslands and shows different responses to disturbances (Stapp et al., 2008). The ecosystem is dominated by grasses; specifically, it's characterized by short monostructure grasses composed of blue grama (*Bouteloua gracilis*) and buffalo grass (*Bouteloua dactyloides*) (Lauenroth, 2008). Both are perennial warm season (C_4) grasses. Another impact of periodic droughts is the low number of shrubs present in this environment, which include saltbush (*Atriplex canesens*), rabbit bush (*Chrysothamnus nauseosus*), plains prickly pear cactus (*Opuntia polyanthemos*), and soapweed yucca (*Yucca glauca)*. Low precipitation levels make the shortgrass steppe less resilient (measure of the amount of time needed to return a system to the equilibrium before the disturbance (Ives, 1995)) and resistant (ability to absorb changes through time (Sutherland, 1974)) to disturbances such as gravel mining than systems that receive more water.

Gravel mining causes environmental disturbance by changing the landscape from undeveloped agricultural land into a hole in the ground, and this process destroys habitat (Langer & Arbogast, 2002). The vegetation structural changes could be as simple as plants no longer standing upright due to compaction of mine vehicles or as drastic as plants being completely removed with the removal of soil at the mine extraction site. Structural changes contribute to changes in resource and substrate availability. For example, much of the overburden used in surface mine reclamation is deficient in both nitrogen and phosphorus (Sengupta, 1993). Sunlight availability also increases in mined areas previously occupied by standing vegetation, and increased light availability is one reason invasive weeds become so abundant in disturbed areas (Tilman, 1986).

Restoration of degraded landscapes is an important process of returning – in a timely manner – ecosystems disturbed by human caused activities such as agriculture, oil extraction, and aggregate mining (Drew et al., 2002) back to a condition of functioning within normal ranges of its reference ecosystem (SER, 2004). Without restoration, damage caused to the ecosystem by erosion, decreased productivity, invasion of exotic species and loss of biodiversity will have long term negative impacts (Bradshaw, 2002).

In the absence of intervention, impacted ecosystems could cause pollution and risk to human health (Ng, 2002). Restoration will not create an ecosystem identical to the one prior to the disturbance, but it should rehabilitate the environment by rebuilding or replacing ecological structures that will function in a manner similar to the previous environment (Choi, 2007).

Great need exists to evaluate reclamation success for grasslands. Ruiz-Jean and Aide (2005) examined 68 restoration studies published between 1996 and 2003. Many of these studies dealt with restoration projects of wetland or forested areas. Only 13 of these studies examined grassland or prairie restoration, and of these 13, only four studied reclamation from mining disturbance (Cullen & Wheater, 1993; Chapman & Younger, 1995; Corbett et al., 1996; Bisevac & Majer, 1999). None of the grassland studies were conducted on the shortgrass steppe but instead were conducted in U.S. tall grass prairie, Australian grassland, or European grassland. The results from these reclamation studies generally showed that such efforts are effective in increasing species diversity and biomass (Bisevac & Majer, 1999).

The Society for Ecological Restoration (SER) recommends nine ecosystem attributes to be used as guidelines for assessing restoration success (SER, 2004). These nine attributes include: similar species in the restored ecosystem compared to a reference site, abundance of native species, correct functional groups for continued ecosystem development, physical environment capable of providing needs for continued development, community showing function for a its stage of succession, community integrated into the broader ecological matrix, elimination of threats from surrounding degraded landscapes, community resilient to normal stresses, and self-sustainable community (SER, 2004). Because assessing all nine attributes is difficult due to financial and time constraints, it has been recommended that at least three areas be measured to assess ecosystem function: species diversity, vegetation structure, and ecological processes (Ruiz-Jaen & Aide, 2005). These functional parameters were investigated in the study using the following hypotheses: (1) Vegetation composition of reference sites is significantly different from the PLC (a reclamation site); (2) Species diversity of reference sites is greater than the PLC; (3) Biomass of reference sites is significantly greater than the PLC; (4) Soil characteristics of reference sites are significantly different from the PLC; (5): Functional group composition of reference sites are significantly different from the PLC; (6) Heterogeneity of reference sites are significantly less than the PLC.

Methods

Characteristics of the Sites

Three locations on the shortgrass steppe in northeastern Colorado were chosen for this study: a gravel mine reclamation site located on the PLC and two reference sites located on the Shortgrass Steppe Long-Term Ecological Research Site (SGS LTER) of the Pawnee National Grasslands.

The PLC located in Weld County, Colorado adjacent to the Cache la Poudre River (40°26'35" N latitude, 104 °48'55" W longitude) with an average elevation of 1437 meters and annual precipitation of 34.5 cm. The PLC soil is characterized by Ascalon Loam, Aquolls and Aquents Gravelly Substratum and Columbo Clay Loam (USDA NRCS 1980). It was actively mined for sand and gravel from 1986-2003. Prior to mining, this area showed a heterogeneous landscape consisting of 26.3 hectares of shortgrass steppe, wetland, and riparian/terrace habitat (Resh & Chimmer, 2005). The influence of the Cache la Poudre River has provided some complexity to the site, allowing patches of taller grasses to occur in the year-round moister conditions of riparian areas. This site was chosen because of specific knowledge of the active reclamation plan (Tschillard et al., 2006). In addition, the site offers research opportunities as part of their focus of offering active inquiry-based education to K- 16 students.

Active gravel mining was terminated on the site in 2003 and the removal of overburden was completed in 2006. A 7.3 hectare augmented lake was created on the site and the topography was returned to a state similar to that of pre-mining. In 2006, the site was tilled and seeded with a twelve-seed grass mix containing the following species: sideoats grama (*Bouteloua curtipendula),* blue grama (*Bouteloua gracilis),* alkaligrass (*Puccinellia nuttalliana*), alkali sacaton (*Sporobolus airoides),* little bluestem (*Schizachyrium scoparium*), needle and thread (*Hesperostipa comata),* switchgrass (*Panicum virgatum*), western wheatgrass (*Agropyron smithii*), Indian ricegrass (*Achnatherum hymenoides*), yellow Indiangrass (*Sorghastrum nutans*), prairie junegrass (*Koeleria macrantha*) and sand dropseed (*Sporobolus cryptandrus*) at a density of 20.3 kg/hectare. The seeds were then covered with weed-free straw mulch to prevent soil erosion. No native forbs were included in the replanting efforts. The site has also been managed to control the invasion of noxious weeds through a combination of methods such as manual removal, herbicide, and mowing. In addition, a localized biological control, *Aceria malherbae* (bindweed mite), has been utilized to control *Convolvulus arvensis*. Although at this stage of reclamation noxious weeds are being targeted, they are advantageous in the initial establishment of groundcover which helps to mitigate the impact of erosion.

The other research locations are at the Shortgrass Steppe Long-Term Ecological Research (SGS LTER) located approximately 40 km north of Greeley, Colorado. The SGS LTER is composed of the USDA ARS Central Plains Experimental Range (CPER) forming the western boundary and the adjacent USDA Forest Service Pawnee National Grassland (PNG) forming the eastern region of the site. (Lauenroth et al., 2008). The CPER is a continuous 6280 ha block of land (40°49' N latitude, 104 °47" W longitude) and was established by purchasing the land from farmers and ranchers unable to keep their land following the dust storms and drought of the 1930's. Cattle grazing has occurred on the CPER since 1939 (Lauenroth & Milchunas, 1991a). The Pawnee National Grassland is composed of 78,100 ha of public land that lies within a patchwork of private land. Average yearly precipitation for this site is 32.1 cm (Lauenroth et al., 2008). Blue grama (*Bouteloua gracilis*) with buffalo grass (*Buchloe dactyloides*) dominate plant communities of the SGS LTER (Singh et al., 1996).

Two sites located on the CPER served as reference sites. Specifically, one of the reference sites was located in Colorado Township 10N, Range 65W, Section 17 (40˚50'7 N latitude, 104˚41'19" W longitude) and the other was located in Colorado Township 10N, Range 65W, Section 27 (40˚48'32" N latitude, 104˚45'36" W longitude). The site located in Section 17 is referred to as Pawnee 17 or Pawnee site 17 throughout this document and the site located in Section 27 is referred to as Pawnee site 27 or Pawnee 27. These areas were chosen as reference sites because they were similarly located in close proximity to a stream; Little Owl Creek for Pawnee 27 and Eastman Creek for

Pawnee 17. Loamy soils were identified at these locations similar to the soil type located at the PLC. Specifically, site 27 was characterized by Nunn Clay Loam surrounded by Ascalon Fine Sandy Loam, site 17 was characterized by Avar Fine Sandy Loam, (Crabb, 1982). In addition, from initial observations these sites appeared to have similar plant composition to the PLC. Another possible reference site located on the Pawnee Grassland was explored but not selected because of greater distance from the selected reference sites. One difference of the selected reference sites from the PLC is that both of these sites have been exposed to moderate cattle grazing (Ashby personal communication 2010). Although it is difficult to find areas on the shortgrass steppe that have not been impacted by humans, these selected sites represent areas that could be considered mature in terms of shortgrass steppe structure and will function as possible endpoints in considering the PLC being restored to a functional equilibrium.

Forty random 1 m^2 plots were permanently marked at the PLC as well as from two locations (Pawnee 17 and 27) on the shorgrass steppe LTER site (n=40; N=120) (Figure 1, 2, 3, and 4). Plots were placed at least 2 m apart to maintain independence. Percent species cover was determined for each plot during peak biomass from July 20 – 24, 2010 (a species list is in Appendix A; nomenclature follows Snow, 2007). In addition to recording percent cover, above ground and below ground biomass data were collected utilizing a 8 cm diameter, 18 cm tall (0.9 liter) soil sampling auger with three collection locations per plot. Any plant material located above the cylinder was collected as above ground biomass, while below ground biomass was collected from root structure located in the soil collected in the auger. Root structure and litter were separated from soil using a 2mm sieve in the lab. Above and below ground biomass and litter samples were dried at 75 °C in a drying oven for 48 hours prior to being massed. After the belowground biomass, litter and rocks were removed from the soil, the three soil samples from each plot were combined. Ten plots from each site were randomly chosen and soils from these plots were sent to A & L Laboratories Inc. for analysis of estimated nitrogen release (ENR), pH, Ca, Mg, K, P and soil organic matter (SOM).

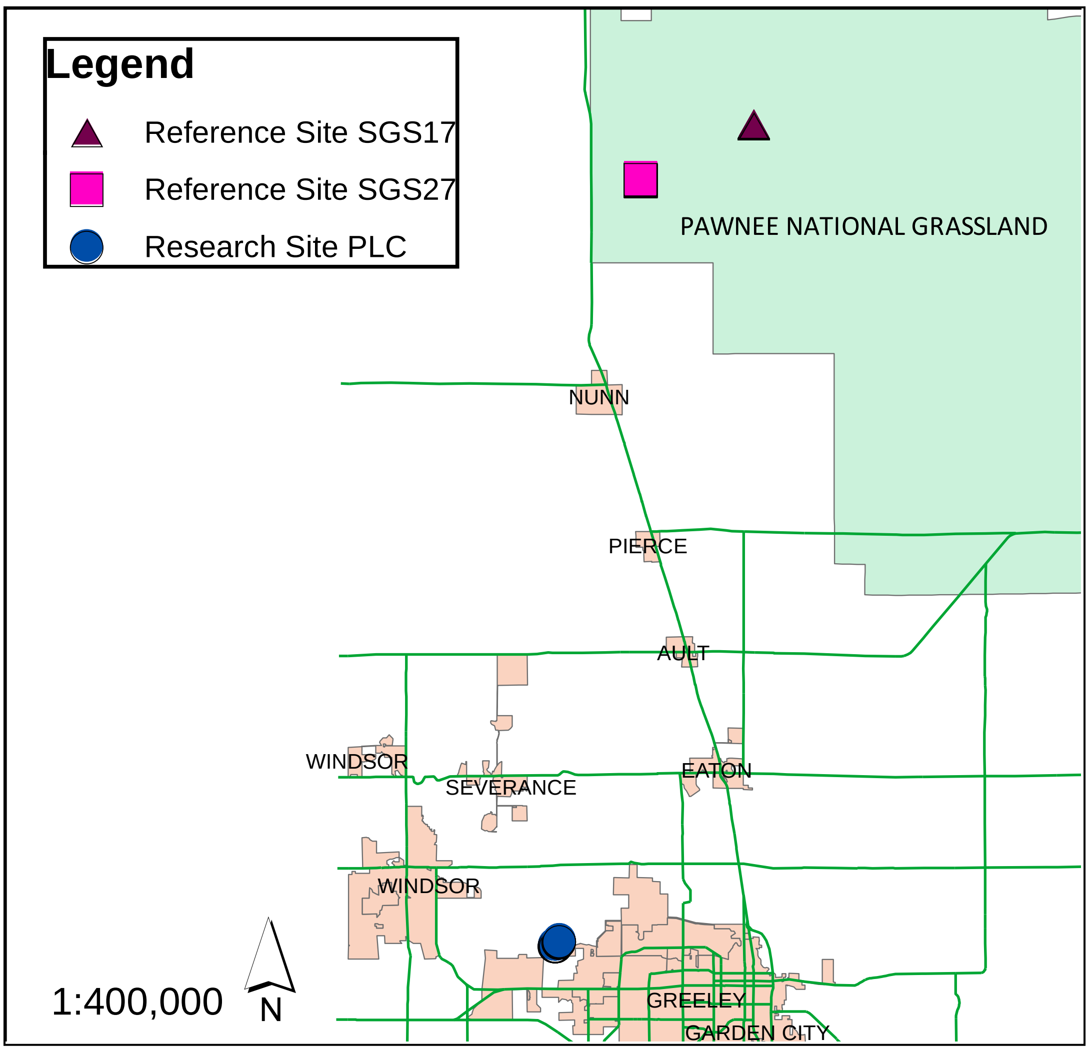


Figure 1. Location of the research sites: Poudre Learning Center and two reference sites. The south reference site is Pawnee Grassland Site 27 (SGS27) and the north reference site is Pawnee Grassland Site 17 (SGS17).

Figure 2. Locations of the 1 m^2 plots at the Poudre Learning Center. Plots were located in two distinct regions of the Poudre learning Center, CO (306 ft = 93.27 m).

Figure 3. Location of the 1 m^2 plots at site 17 on the Pawnee Grassland, CO (200 ft = 60.96 m).

Figure 4. Location of the 1 m^2 plots at site 27 on the Pawnee Grassland, CO (200 ft = 60.96 m).

Procedures

To test hypothesis 1, overall averages for vegetative cover, amount of bare ground, and amount of litter present was determined. To determine if average cover, bare ground and litter were significantly different, an MANOVA was run. In addition, the software program PC-ORD 5.10 was utilized to determine if sites were similar to each other in terms of community composition. A nonmetric multidimensional (NMS) ordination was performed utilizing the percent cover data for each of the plots at each site. Specific parameters for this test included a Sorensen (Bray-Curtis) distance measure with 50 runs with the real data and two axes; the stability criterion was set at 0.00001 with 15 iterations. The maximum number of iterations was set at 100 with step down in dimensionality. The initial step length was 0.20 with random numbers serving as the source (100 randomizations). To statistically verify the visual differences observed from the ordination, a multi-response permutation procedure (MRPP) analysis was performed using the same distance measure.

Species composition was also investigated utilizing abundance and frequency (Bonham, 1989) measurements calculated from percent cover data in each plot. From these measurements, an indicator species analysis (McCune & Metford, 2006) was performed to determine which species were characteristic of the three sites. Interpretation of the analysis was based on a strong, moderate and weak indicator criterion with strong indicators having a value > 50%, moderate species having values between 25-50% and weak species having a value of < 25% with a cutoff at 5%. A Monte Carlo test of significance was run to determine if the observed indicator value was significant.

To compare sites in terms of species diversity (hypothesis 2), richness (number of different species per plot), evenness (Shannon's diversity index/ ln (richness), diversity I (Shannon's diversity index = - sum (Pi*ln(Pi)) where Pi = importance probability in element I relativized by row total), and diversity II (D = Simpson`s diversity index for infinite population = 1 - sum (Pi*Pi) where Pi = importance probability in element i relativized by row total) were determined for each plot. This data were compared across sites. Richness and diversity II where determined not to be evenly distributed so these data were log transformed, analyzed with a MANOVA and if significant, an ANOVA was run with a post hoc Student Newman Keuls test conducted to determine significant differences between the sites.

To address the question of how similar the research site biomass was to the biomass in reference sites (hypothesis 3), measurements of above ground biomass, below ground biomass, litter mass and rock mass were used from 20 randomly selected plots from each site. Determination of normality using Wilks-Shapiro test in SAS 9.2 showed the data were not evenly distributed for all variables except below ground biomass, so data were log transformed and analyzed using MANOVA, followed again by ANOVA and the post hoc Student Newman Keuls test.

Using SAS 9.2, a determination of normality was conducted for soil nutrients. The soils data were not normally distributed (Wilks-Shapiro test $p<0.0001$); therefore, the data were transformed. Organic matter was first sine arc transformed because it was recorded as a percent and then log transformed. All other data for the variables were log transformed. Analysis was the same as with biomass.

To test hypothesis five, investigating the question of how similar ecosystem function was between the research site and the reference sites, plant species were categorized into different functional groups. Sites were compared based on functional group composition of plots located at each site. These functional group classifications included annual cold season (C_3) graminoids, annual warm season (C_4) graminoids (C_3), perennial cold season graminoids (C_3), perennial warm season graminoids (C_4), annual forbs, perennial forbs, and perennial shrubs (see Appendix A). The dominance of these functional groups was compared between sites using NMS ordination. A MRPP analysis was used to determined if sites where significantly different from each other in terms of functional groupings. Characteristic functional groups were also examined by an indicator species analysis (McCune & Metford, 2006). Interpretation of the analysis was as above. A Monte Carlo test of significance was run to determine if the observed maximum indicator value for each indicator was significant.

Because there were three data points from each plot, an examination of variability as a proxy for heterogeneity was possible. To test for such heterogeneity of the sites, a coefficient of variation (standard deviation/mean) was calculated for each plot for above ground biomass, belowground biomass, and litter. The calculated values were then analyzed using an ANOVA after the data were log transformed; the data were not normally distributed.

In addition to comparing among sites, the two locations (north and south) at the PLC were analyzed to determine if differences existed within the PLC. These sites had slightly different gravel mine impacts, with the northern site being churned and dug up through the mining process, while the southern site was adjacent to a mining road and had overburden placed over it. Soil data and biomass data from these locations were compared to each other using an ANOVA test and again a student Newman Keuls post hoc analysis.

Results

Vegetation composition was different at the PLC compared to the two reference sites on the Pawnee Grassland. The PLC had more bare ground than the reference sites, more litter, and less ground cover (Table 1), but these differences were not significantly different. Non-Metric Multidimensional Scaling Ordination, based on percent cover for species present at each plot, showed distinct groupings (Figure 5). Some of these areas do overlap, indicating some similarity among these groups; the PLC site and Pawnee Grassland site 17 showed the greatest overlap (Figure 5). However, an MRPP (T-test =

-44.61, $p < 0.001$, observed delta = 0.597, expected delta = 0.724) test determined the three sites to be significantly different. A community similarity analysis was conducted to determine the percent similarity for species groundcover for the sites. The PLC was 18.5% similar to Pawnee 27 and 42.6% similar to Pawnee 17. When compared to each other the Pawnee sites were 34.9% similar. In terms of difference of average cover, litter and bare, no significant difference were seen among site (F-test = 1.96, $p = 0.1613$).

Indicator species analysis showed marked differences between the two references sites and the research site. The PLC was characterized by the strong indicator species *Bromus tectorum, Convolvulus arvensis,* and *Elymus smithii*. Both *Bromus tectorum* and *Convolvulus arvensis* are classified as noxious weeds in Colorado. Pawnee 27 was characterized by strong indicator species of *Cirsium flodmanii*, *Equisetum laevigatum,* and *Ratibida columnifera* along with moderate indicator species *Sphaeralcea coccinea*. Pawnee 17 was characterized by strong indicator species, *Cleome serrulata* and *Sporobolus airoides*, along with moderate indicator species, *Chenopodium incanum* var. *incanum, Elymus smithii, Sisymbrium altissimum,* and *Sophora nuttalliana* (Table 2). In addition, the PLC showed greater amounts of invasive species than either of the Pawnee sites (Figure 6).

Richness ($F = 85.4$, $p < 0.001$) and diversity (Shannon $F = 20.5$, $p < 0.0001$; Simpson $F = 7.7$, $p = 0.0007$) values were also significantly different between sites. Pawnee site 27 had the greatest number of species (richness) and was significantly higher than both Pawnee site 17 and the PLC. Pawnee site 17 also had significantly more species than the PLC. Using Shannon's diversity index, all three sites showed significant differences from each other ($F = 20.53$, $p < 0.0001$) with Pawnee site 27 showing the greatest diversity and then Pawnee Site 17 followed by the PLC (Figure 7). There was no significant difference in evenness among sites (F = 0.82, p = 0.4442).

Soil characteristics differed significantly among sites for all variables tested (Table 3). For the soil nutrients, the PLC had significantly lower amounts of available phosphorus and potassium, but higher amounts of calcium and magnesium (Figure 8), which may also explain the significantly higher pH at PLC (Figure 8). Soil organic matter and estimated nitrogen release were also lower for the PLC while cation exchange capacity was higher (Figure 9).

Table 1. Average ground cover measurements for three sites in Colorado; two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). None of the values were significantly different.

	% Ground Cover	% Bare	% Litter
Pawnee 27	78.5	5.5	16.0
PLC	68.8	7.5	23.7
Pawnee17	90.0	1.7	8.3

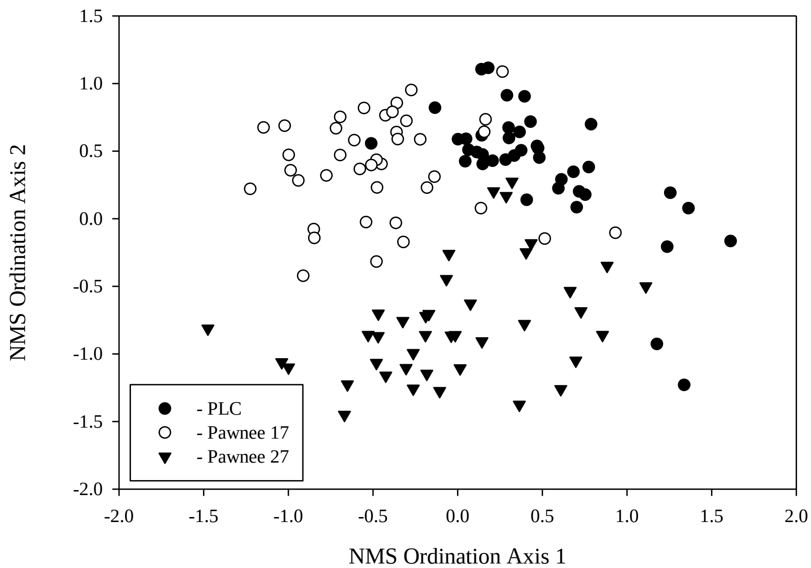


Figure 5. Non-Metric Multidimensional Scaling Ordination from 40 plots each at the Poudre Learning Center (PLC), and two sites on the Pawnee Grassland (Pawnee 17 & 27).

Table 2. Indicator species analysis of three sites on the shortgrass steppe in Colorado; two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Indicator species by site based on releative abundance and relative frequency of species from each site. Species colored red are noxious weeds for Colorado.

Site		
Pawnee 27	PLC	Pawnee 17
Artemisia frigida[3]	*Bromus tectorum*[1]	*Bouteloua gracilis*[3]
Bouteloua dactyloides[3]	*Achnatherum hymenoides*[3]	*Carex stenophylla*[3]
Bouteloua gracilis[3]	*Convolvulus arvensis*[1]	*Chenopodium incanum* var. *incanum*[2]
Carex stenophylla[3]	*Elymus smithii*[1]	*Cleome serrulata*[1]
Cirsium flodmanii[1]	*Sporobolus airoides*[3]	*Descurainia pinnata*[3]
Conyza canadensis[3]	*Sporobolus cryptandrus*[3]	*Elymus smithii*[2]
Elymus elymoides[3]		*Hordeum jubatum*[3]
Elymus smithii[3]		*Juncus arcticus* var. *balticus*[3]
Equisetum laevigatum[1]		*Lactuca serriola*[3]
Hesperostipa comata[3]		*Sisymbrium altissimum*[2]
Heterotheca villosa[3]		*Sophora nuttalliana*[2]
Lepidium densiflorum[3]		*Sporobolus airoides*[1]
Lithospermum incisum[3]		
Nassella viridula[3]		
Potentilla pensylvanica[3]		
Ratibida columnifera[1]		
Sphaeralcea coccinea[2]		
Symphyotrichum falcatum[3]		
Taraxacum officinale[3]		
Trifolium repens[3]		

[1] - Strong indicator species with indicator values >50%

[2] - Moderate indicator species with indicator values 25%-50%

[3] - Weak indicator species with indicator values 5%-25%

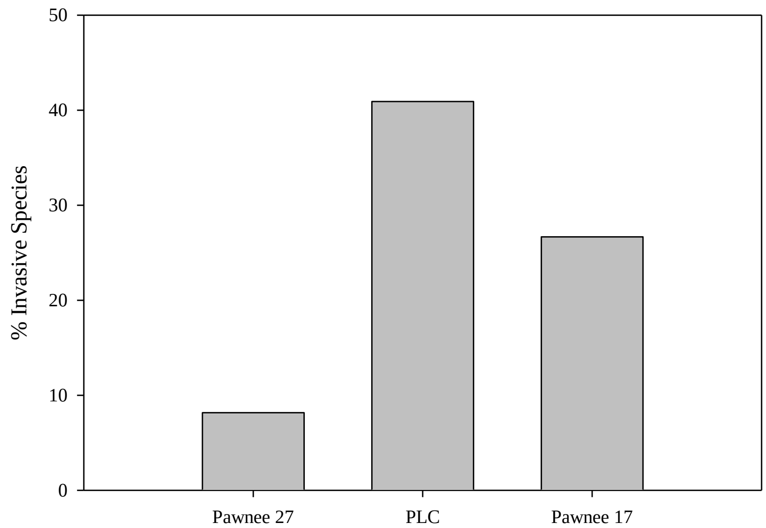


Figure 6. Percentage of invasive (non-native) species at the mine reclamation site Poudre Learning Center (PLC), and two reference sites on the Pawnee Grassland (Pawnee 17 & 27).

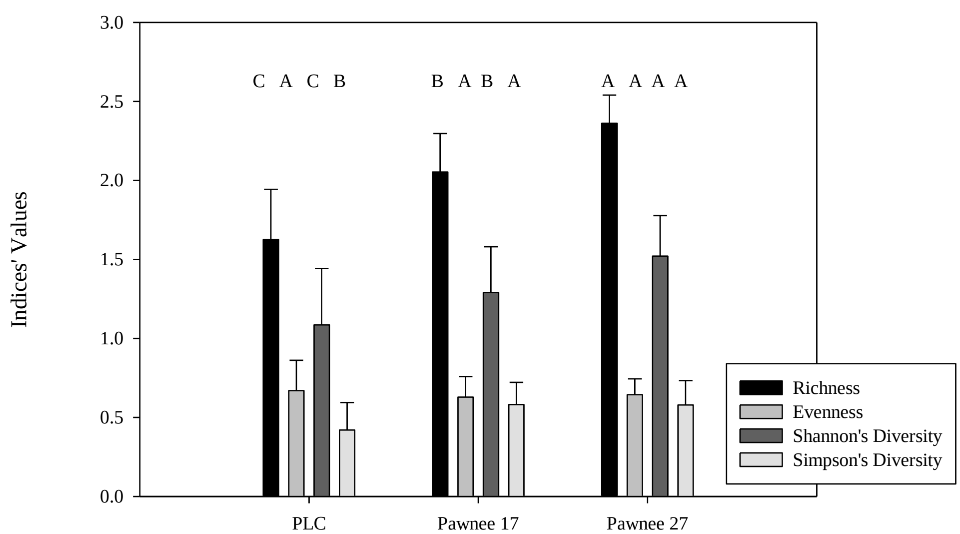


Figure 7. A comparison of the means for richness, evenness, Shannon's Diversity Index, and Simpson's Diversity Index from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Error bars represent standard deviations. Data for richness were log transformed. Different letters indicate significant differences between sites.

Table 3. Results of an ANOVA of soil characteristics from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). All data were log transformed prior to ANOVA.

Variable	F – Value	P – Value
Organic Matter (%)	65.07	<0.0001
Estimated Nitrogen Release (kg/ha)	71.6	<0.0001
Phosphorus (mg/kg)	24.34	<0.0001
Potassium (mg/kg)	95.03	<0.0001
Magnesium (mg/kg)	57.02	<0.0001
Calcium (mg/kg)	22.45	<0.0001
pH	7.26	0.0016
Cation Exchange Capacity (mmol/kg)	21.95	<0.0001

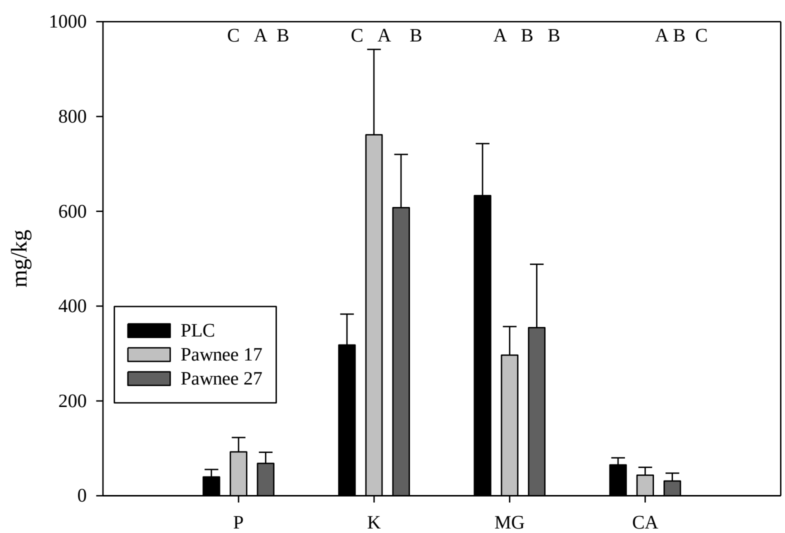


Figure 8. Nutrient loads from three sites on the shortgrass steppe in Colorado, two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Letters represent significant differences. Calcium data were divided by 10 to display on the figure.

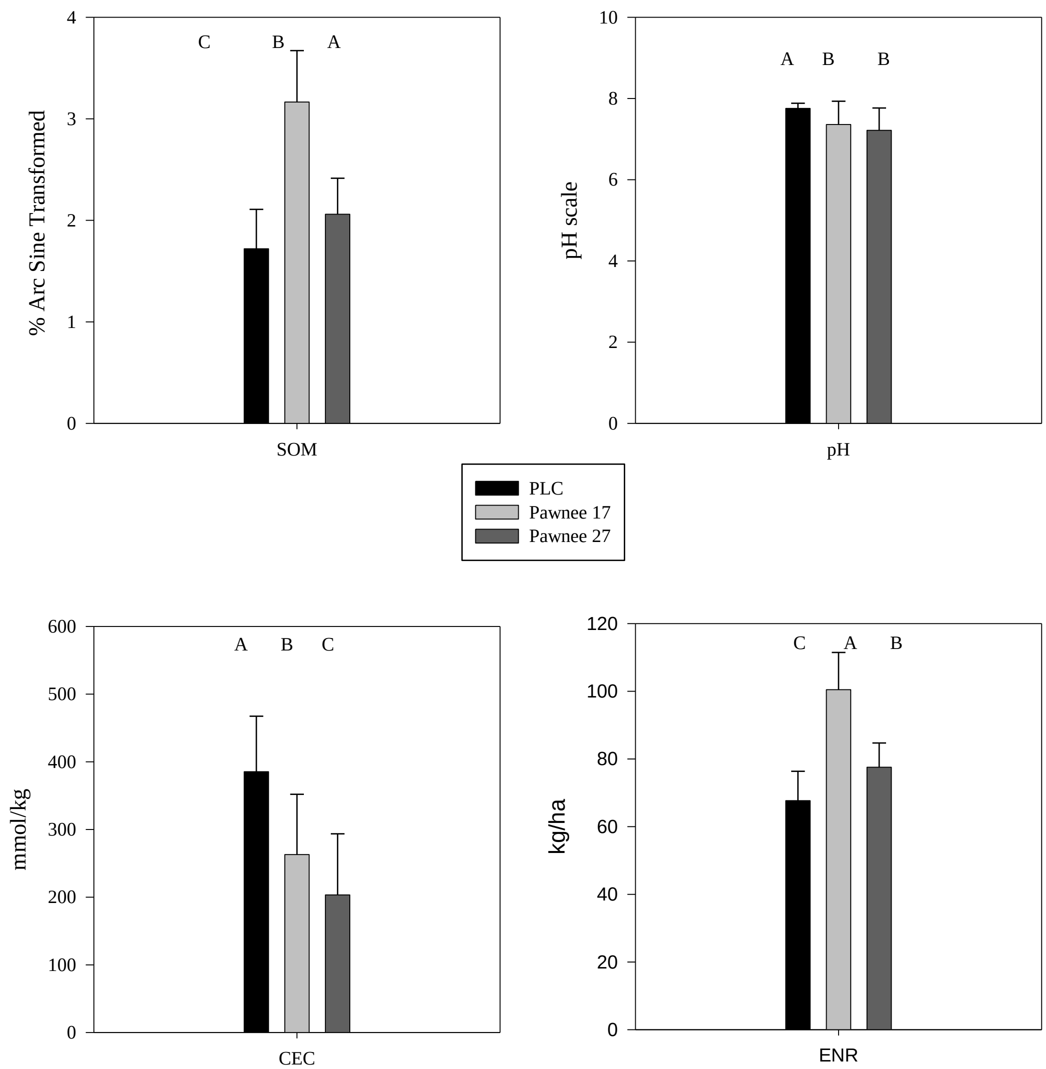


Figure 9. Soil nutrient characteristics at three sites. Letters indicate significant differences between variables from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Error bars represent standard deviations. SOM represents soil organic matter, CEC represents cation exchange capacity, and ENR represents extimated nitrogen release.

Above ground and below ground biomass measurements for the sites were significantly different from each other as were the amounts of litter and rock. The measurement of the ratio of shoot biomass to root biomass also showed a significant difference (Table 4). Above ground biomass was the least at the PLC but not significantly different from Pawnee 17 or Pawnee 27; rather, the Pawnee sites were different from each other. Below ground biomass was significantly lower for the PLC compared to both reference sites although between the Pawnee sites, Pawnee Site 17 did have significantly more belowground biomass than Pawnee 27. The PLC had intermediate amounts of litter compared to the Pawnee sites (Figure 10): significantly higher than Pawnee 27, but not Pawnee 17. The shoot-to-root ratio was higher for the PLC (Figure 11).

Table 4. ANOVA Results for biomass from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Data were log transformed prior to ANOVA.

Variable	F-Value	P –value
Shoot to Root Ratio	20.84	<0.0001
Rocks	89.45	<0.0001
Litter	20.34	<0.0001
Below Ground	24.79	<0.0001
Above Ground	4.44	0.0162

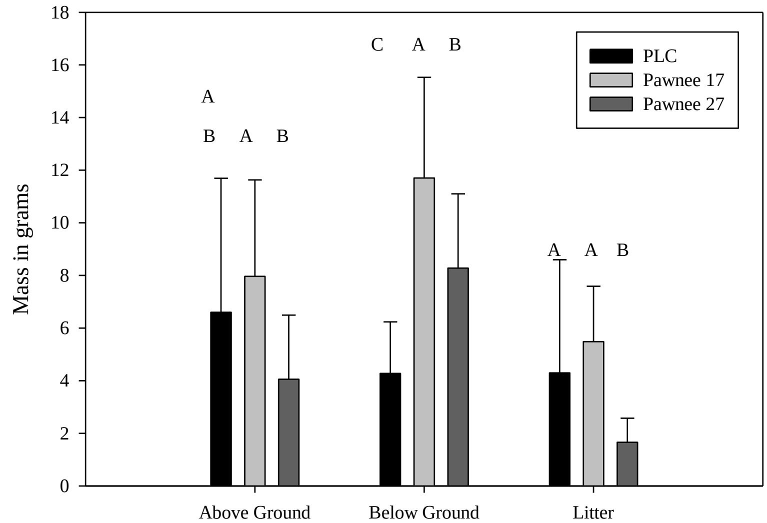


Figure 10. Biomass means. Letters indicate significant differences between variables from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Error bars represent standard deviations.

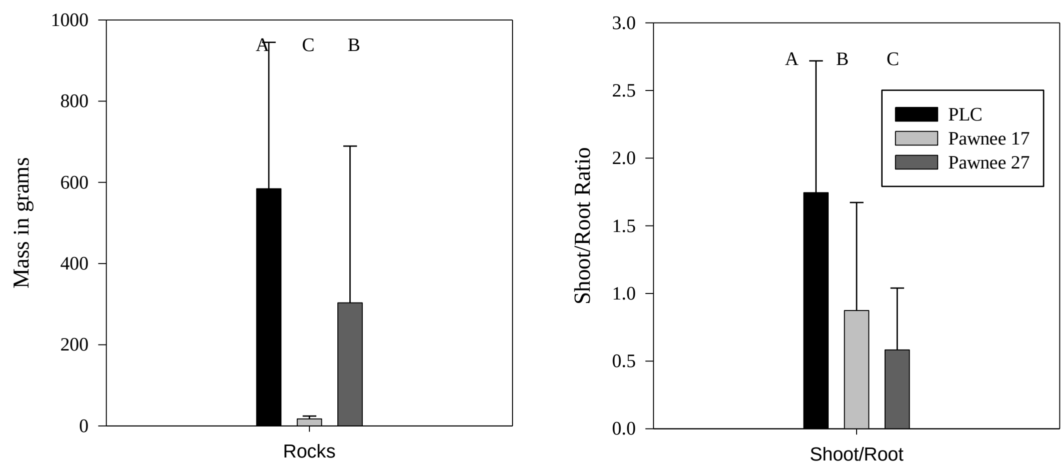


Figure 11. Comparison of rock mass and shoot to root ratios. Letters indicate significant differences between variables from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Error bars represent standard deviations.

The functional group composition was different at the PLC compared to the two reference sites on the Pawnee Grassland. Site ordinations do overlap indicating some similarity among these groups. In particular, the PLC site and Pawnee Grassland site 27 showed the greatest overlap (Figure 12). An MRPP (T-test = -17.45, $p < 0.001$, observed delta = 0.459, expected delta = 0.517) test determined the three sites to be significantly different from each other. A community similarity analysis was also conducted utilizing functional groups and the PLC was 81.8% similar to Pawnee 27 and 63.8% similar to Pawnee 17. The Pawnee sites compared to each other showed 60.3% similarity for functional groups.

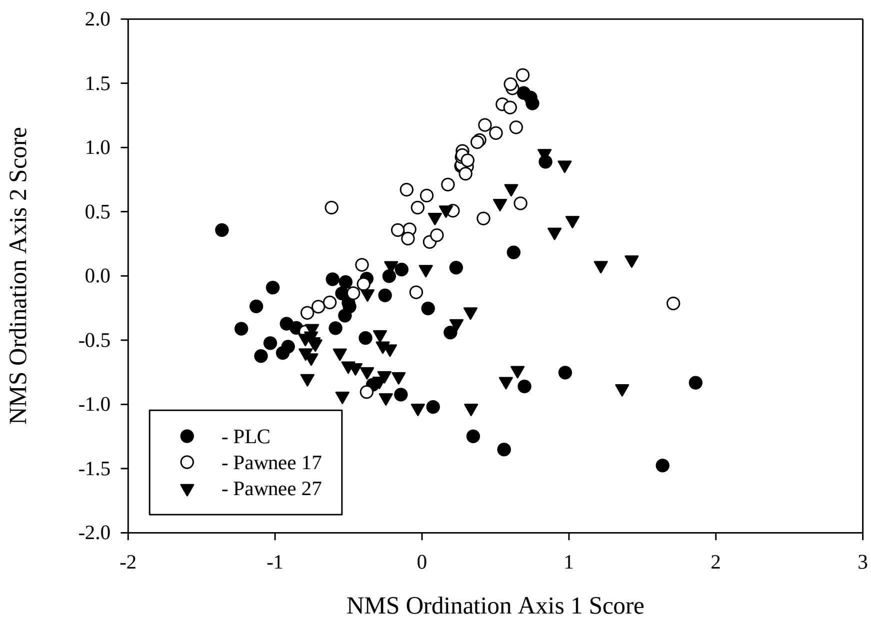


Figure 12. NMS comparison of functional similarity for the mine reclamation site Poudre Learning Center (PLC) and two reference sites on the Pawnee Grassland (Pawnee 17 & 27).

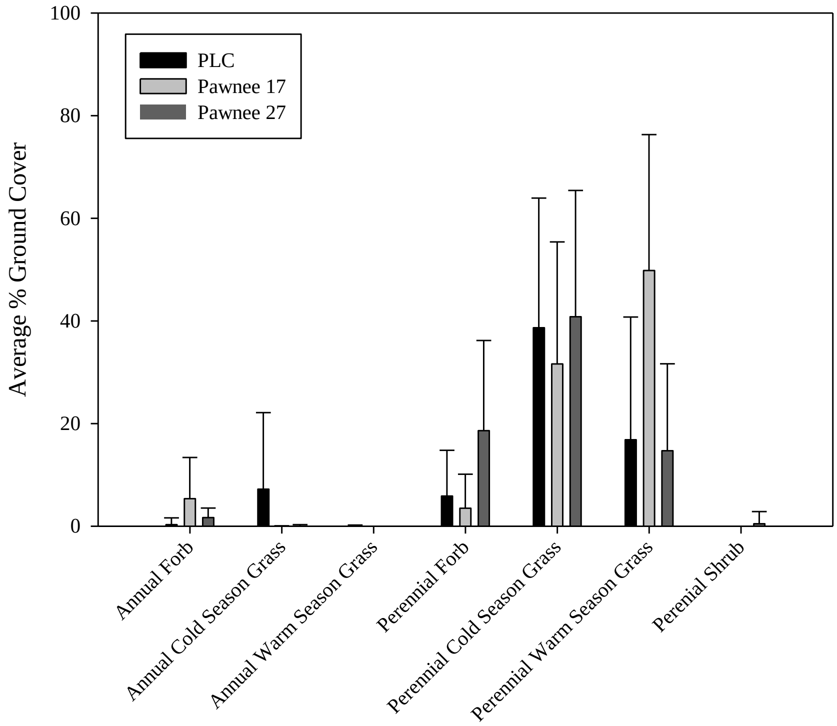


Figure 13. Comparison of abundance of functional groups from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Error bars represent standard deviations.

The PLC showed greater amounts of both warm season and cold season annual graminoids and annual warm season graminoids while Pawnee site 17 was characterized by a greater abundance of perennial warm season graminoids (Table 5, Figure 13). Forbs generally were more common on the Pawnee sites, and one site on the Pawnee (Pawnee 27) was characterized by shrubs. The PLC was characterized by the strong indicator functional group, annual cold season graminoid and moderate indicator group of perennial cold season graminoid. Pawnee site 17 was characterized by the strong indicator functional groups perennial warm season graminoid and annual forb and moderate indicator groups of perennial cold season graminoid. Pawnee site 27 was characterized by the strong indicator group of perennial forb and moderate indicator species of perennial cold season graminoid. All functional groupings were deemed significantly different (Table 5).

Table 5. Indicator values (% of perfect indication, based on combining the values for relative abundance and relative frequency) from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC).

Functional Group	Average	Max	Pawnee 27	PLC	Pawnee 17	P-Value
Annual Forb	28	64	21	1	64	0.0101
Annual Cold Season Graminoid	17	49	0	49	0	0.0101
Annual Warm Season Graminoid	3	8	0	8	0	0.0101
Perennial Forb	29	67	67	14	8	0.0101
Perennial Cold Season Graminoid	32	36	36	32	28	0.3737
Perennial Warm Season Graminoid	30	60	14	16	60	0.0101
Perennial Shrub	5	15	15	0	0	0.0202

The PLC site did not differ significantly in terms of biomass heterogeneity of the site compared to the Pawnee sites when looking at plot variability as measured using the coefficient of variation (Table 6; Figure 14). In terms of litter, the PLC was significantly lower than Pawnee site 27 but the same as Pawnee 17.

Table 6. ANOVA output comparing coeficient of variation utilizing within plot variability for above and below ground biomass and litter from three sites in the shortgrass steppe in Colorado, two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Data were log transformed prior to ANOVA.
.

Coeficient of Variation		
Variable	F – Value	P – Value
Above Ground	1.82	0.1713
Below Ground	2.01	0.1433
Litter	4.76	0.0122

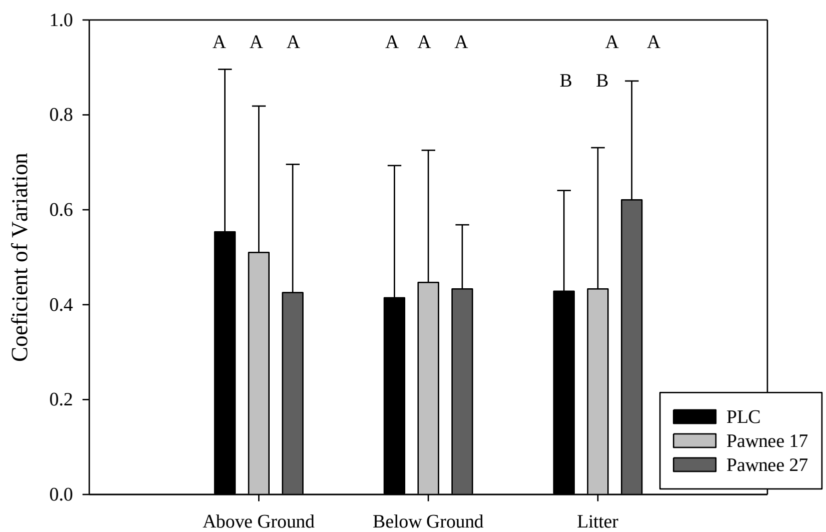


Figure 14. Mean coefficient of variation for above and below ground biomass. Letters indicate significant differences between variables from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC). Error bars represent standard deviations.

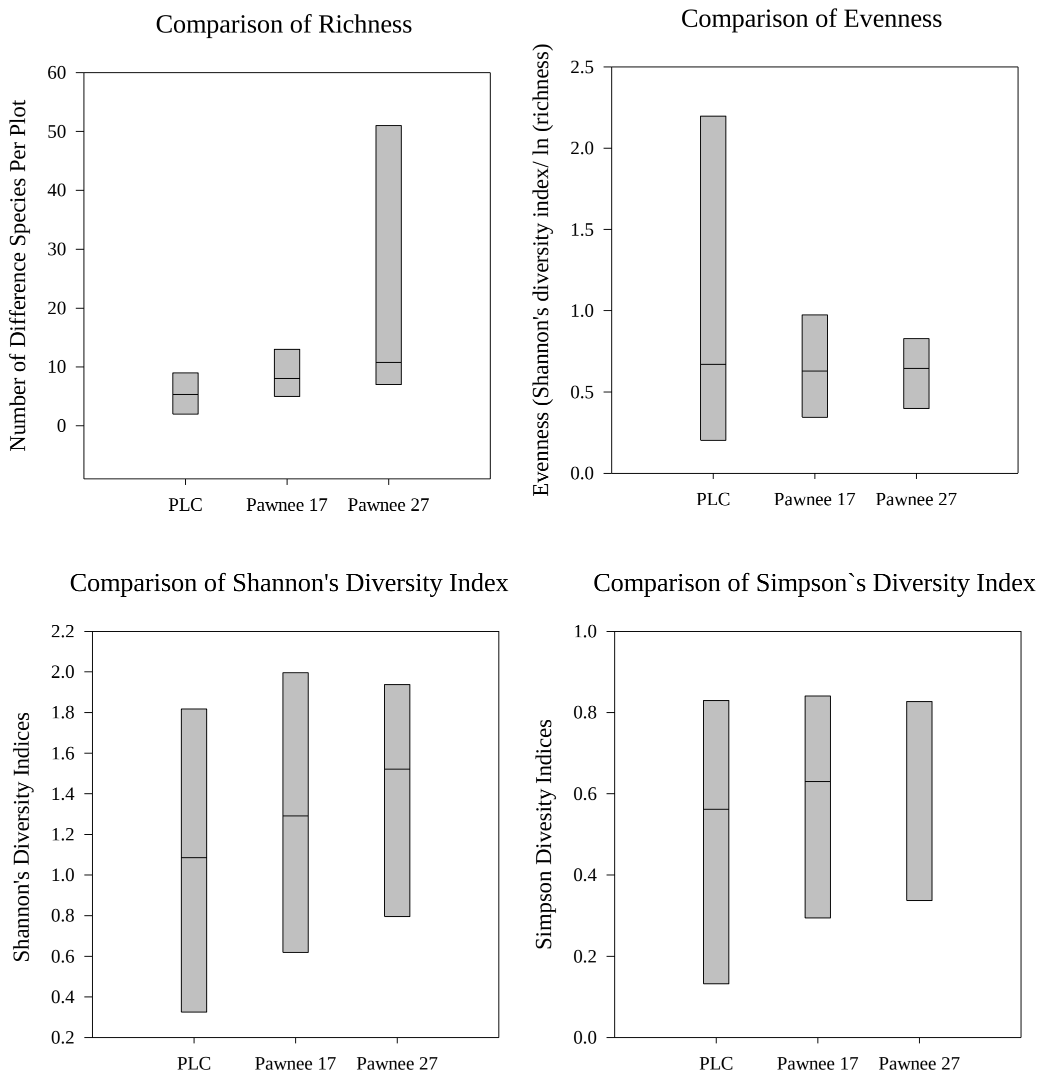


Figure 15. Maximum, minimum and mean measurements of diversity for from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC).

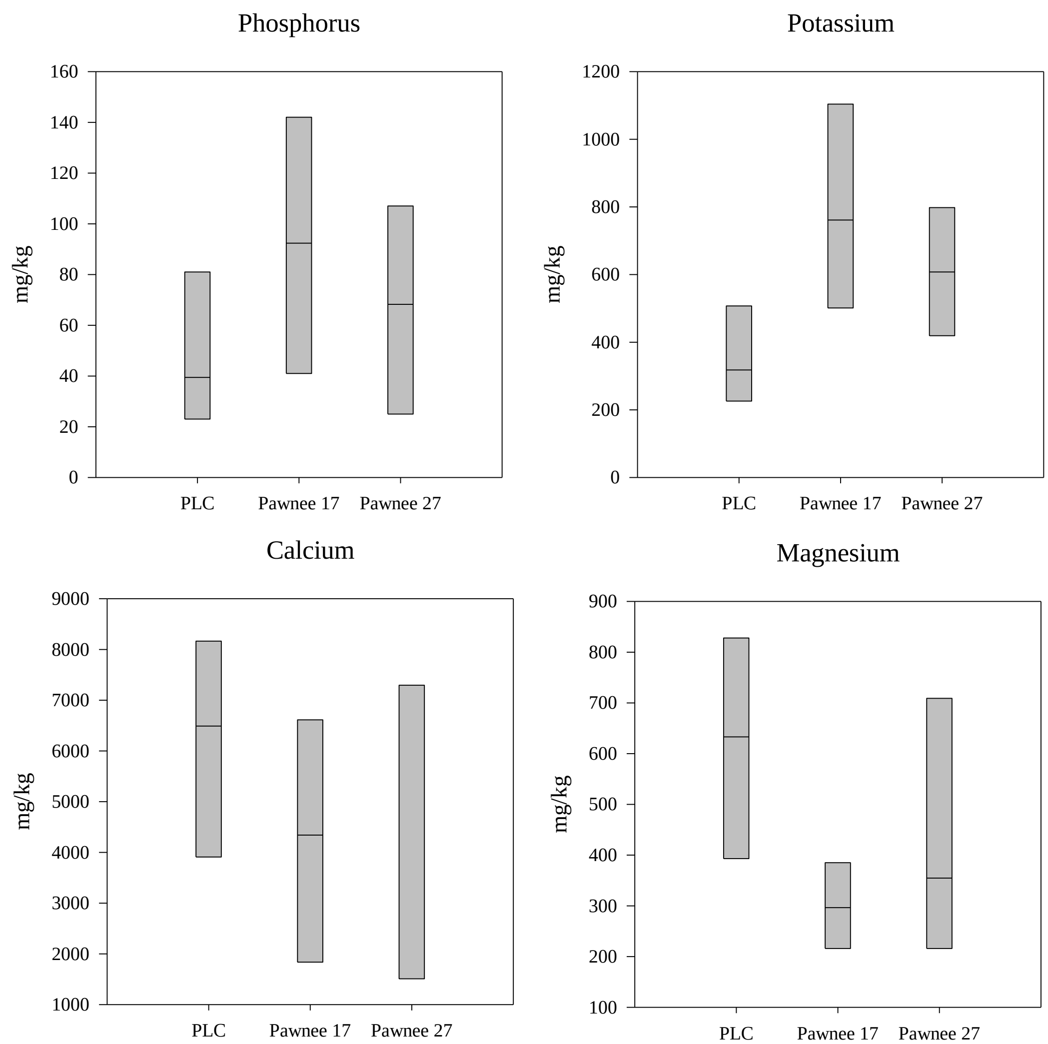


Figure 16. Maximum, minimum and mean measurement of soil minerals from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC).

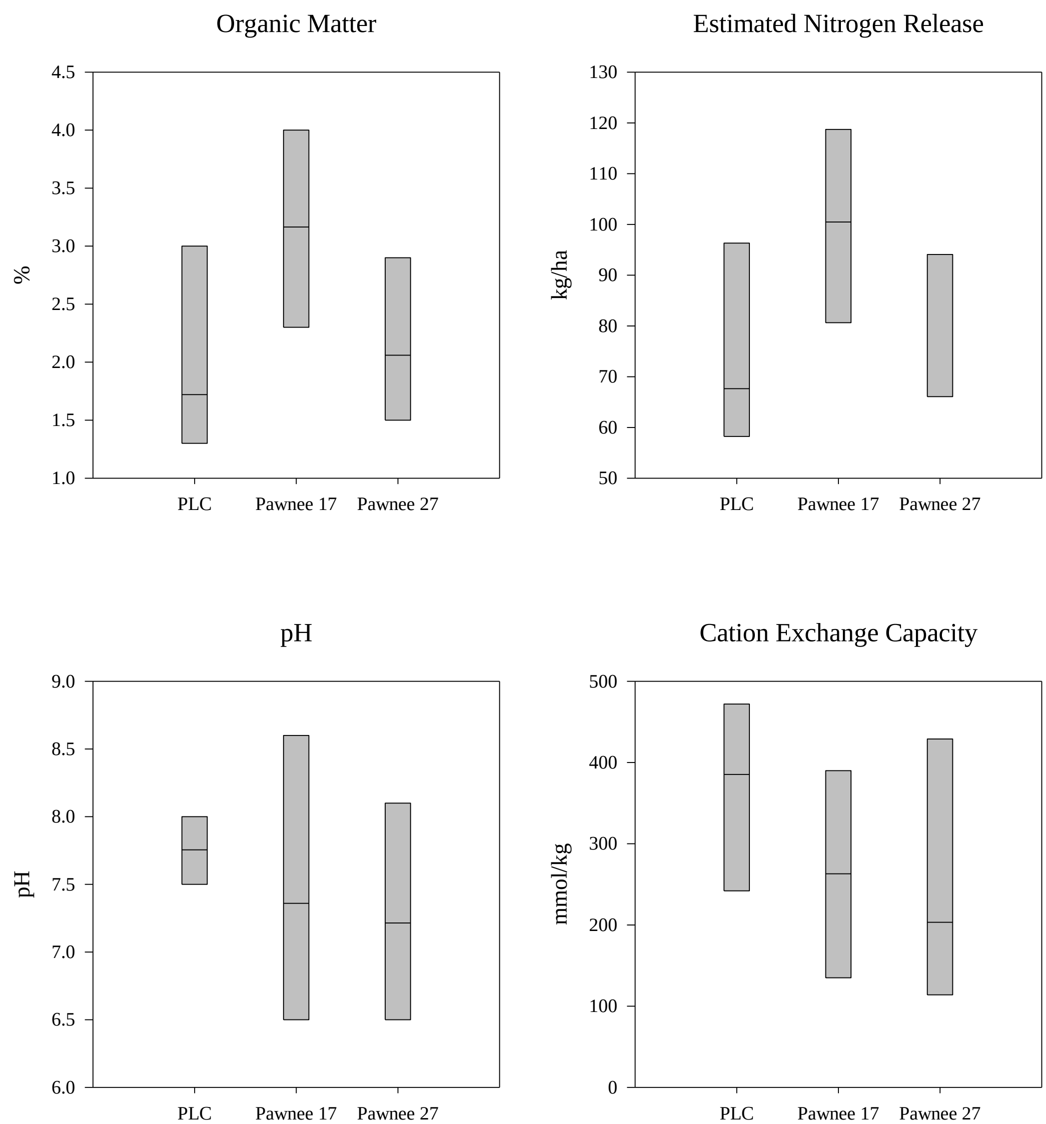


Figure 17. Maximum, minimum and mean measurements for soil characteristics from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC).

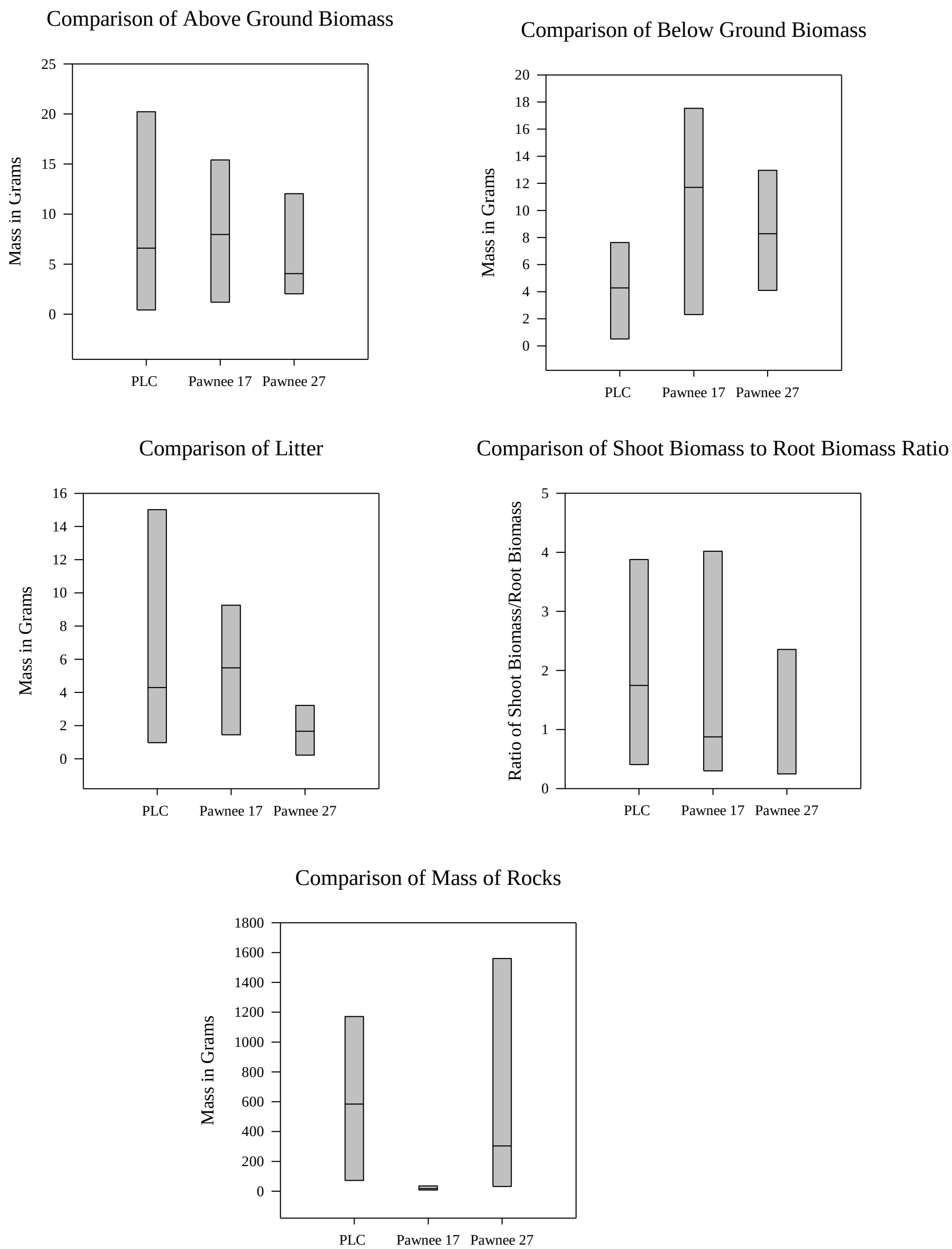


Figure 18. Maximum, minimum and mean measurements from three sites on the shortgrass steppe in Colorado two are reference sites (Pawnee 17 & 27) and one is a mine reclamation site (PLC).

To determine how closely each of the sites were to each other in terms of the measured variables and to determine areas of overlap, maximum and minimum values for each of the variables were graphed (Figures 15, 16, 17, and 18). These graphs indicate that some of the plots at the PLC fall within the parameters of the reference sites.
The two PLC locations differed significantly from each other in terms of rocks and above and below ground biomass (Table 7); the PLC south location had higher amounts of biomass for both above and below (Figure 20). For soil data, all soil characteristics but pH differed by location (Table 8), although not as dramatically as they differed from the Pawnee grassland sites. The southern location showed lower levels of potassium and phosphorus but higher amounts of calcium (Figure 21). The rock composition for the PLC locations differed noticeably as well. The south location had more rocks compared to the north (Figure 19).

Table 7. ANOVA results comparing the biomass of plots located at the mine reclamation site (PLC).

Variables	F-Value	P – value
Shoot/root	0.311	0.5839
Rocks	14.45	0.0013
Litter	1.55	0.229
Below Ground	5.79	0.027
Above Ground	3.81	0.0315

Table 8. ANOVA results comparing soil nutrients for plots located at the P LC.

Variables	F-Value	P – value
Soil Organic Matter	7.18	0.0153
Estimated nitrogen Release	6.8	0.0178
Phosphorus	30.63	< 0.0001
Potassium	5.54	0.0301
Magnesium	6.35	0.0214
Calcium	25.83	< 0.0001
pH	4.37	0.051
Action Exchange Capacity	22.69	0.0002

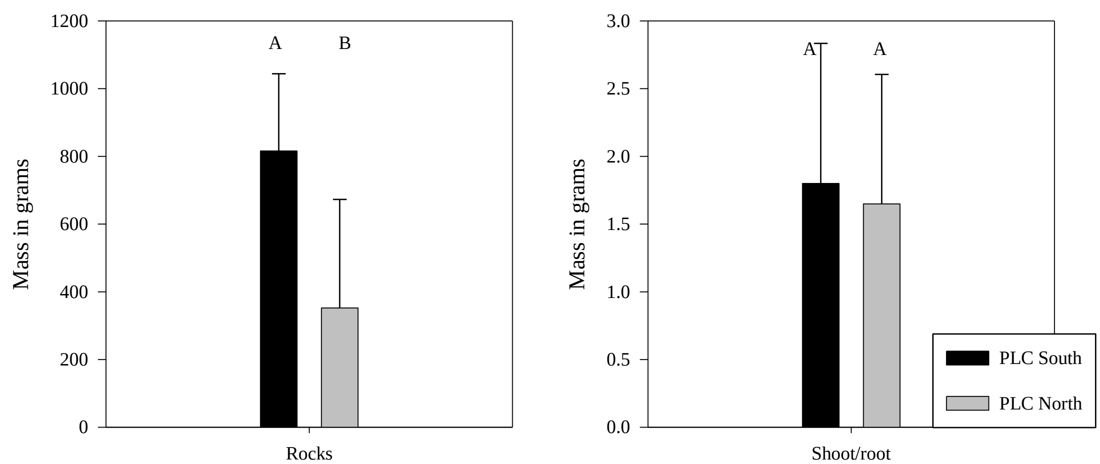


Figure 19. Rock composition and Shoot/root ratios of the mine reclamation site PLC north and PLC south. Letters indicate significant differences between variables. Error bars represent standard deviations.

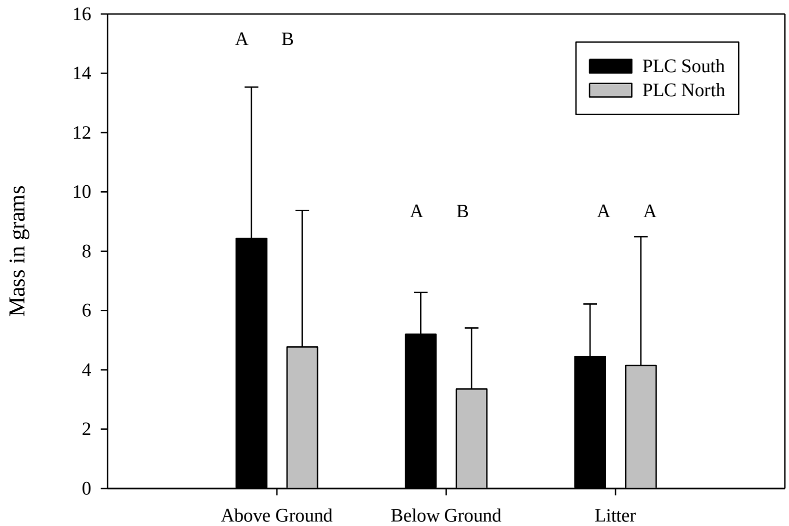


Figure 20. Biomass characteristics for research site PLC north and PLC south. Letters indicate significant differences between variables. Error bars represent standard deviations.

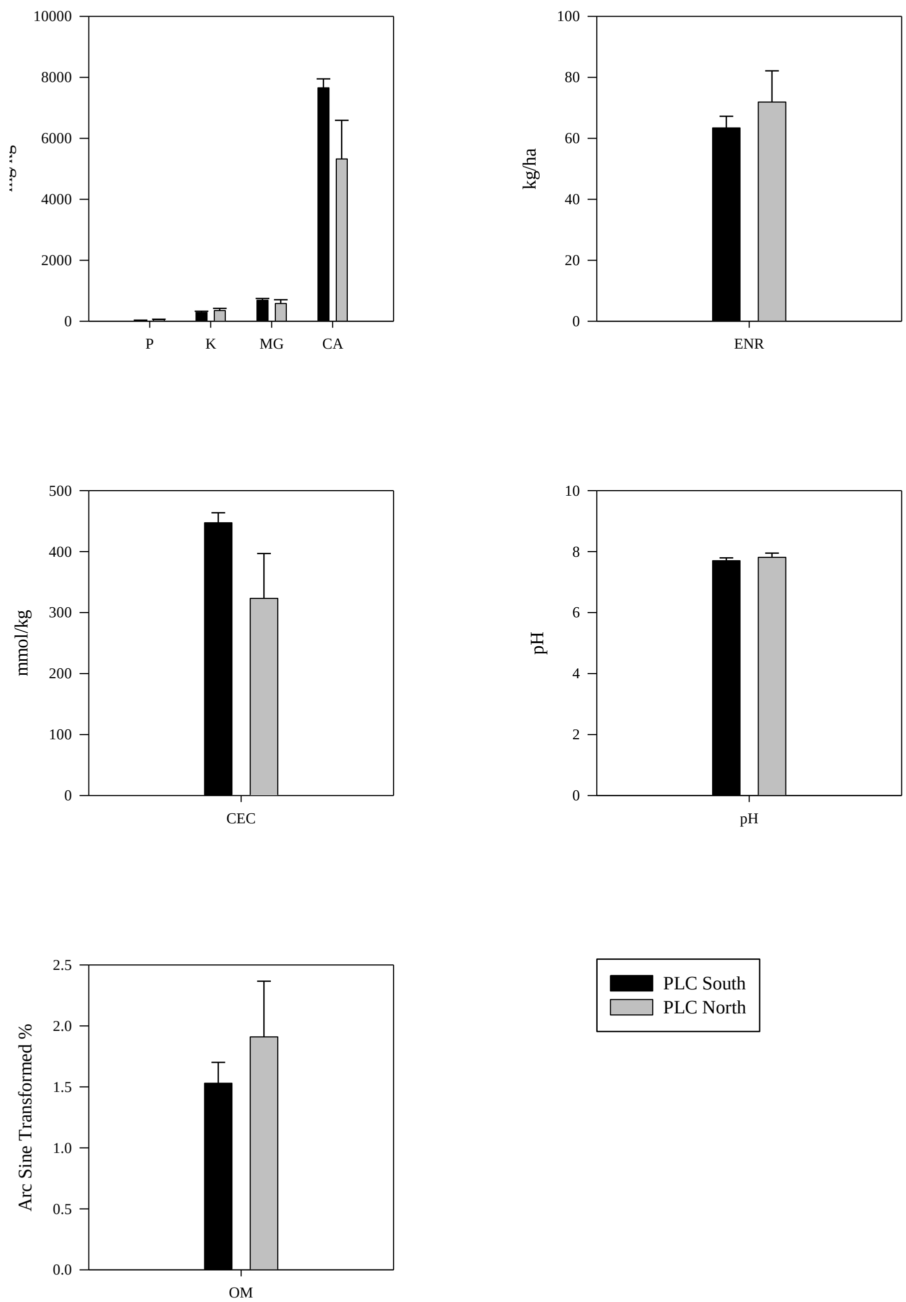


Figure 21. Soil characteristic comparing mine reclamation site PLC north to PLC south. Error bars represent standard deviations.

Discussion

Based on the nine restoration attributes the Society for Ecological Restoration recommends for assessing reclamation success (SER, 2004), the PLC is moving in the direction of full restoration but not yet completely reclaimed. The PLC has less vegetative cover than the reference sites, but does show 69% ground cover overall indicating the success of revegetation efforts.

Hypothesis1, "Vegetation composition of reference sites is significantly different from the PLC," was supported. While some differences are expected due to the heterogeneity of the region (Fuhlendorf & Engle, 2001), significant differences also indicate that the propagule pressure may be different at the PLC than on the Pawnee Grassland with some of the plants located on the Pawnee Grassland sites either not being dispersed to the PLC (Bradshaw, 2000) because intact shortgrass steppe grasslands are about 40 km away or because local plants are failing to successfully colonize. This lack of establishment is evidenced by the lack of dominant species from the planted seed mix. Of the vegetation mixture planted in 2006, only one fourth of species, including *Elymus smithii*, *Achnatherum hymenoides, Panicum virgatum* and *Sporobolus cryptandrus*, were found in research plots. Other grasses planted, including, *Bouteloua curtipendula*, *Hesperostipa comata*, and *Sporobolus ariodes*, were present on the site (personal observations) but not in abundance. In the future, these plants may become better established as succession continues and the dominance of some of the cool season grasses decreases (Munson & Lauenroth, 2011). Reseeding should not be needed.

Although many of the species located on the PLC were different from the Pawnee sites, there were a number of species that did overlap. Nine species were shared by the

PLC and by one or both of the Pawnee sites: *Chamaesyce fendleri*, *Cirsium arvense*, *Descrania pinnata*, *Elymus smithii*, *Panicum virgatum*, *Sporobolus cryptandrus*, *Sporobolus ariodes*, *Tragopogon dubius*, and *Verbenea bracteata*. The presence of the ubiquitous noxious weed *Cirsium arvense* is not encouraging for reclamation progress, but the similarity of the warm season grasses (*Elymus smithii*, *Panicum virgatum*, *Sporobolus cryptandrus*, and *Sporobolus ariodes*) does indicate that progress is being made and that native grasses found on the Pawnee are becoming established at the PLC. The community similarity analysis utilizing species composition showed the PLC being more similar to Pawnee 17 than Pawnee 17 was to Pawnee 27. The similarity between the PLC and Pawnee 17 may be due to the two sites having similar soil texture. Fine sandy loam located at the PLC and Pawnee 17 retains water better than other soils found on the Pawnee Grasslands (Dodd & Lauenroth, 1997). Greater ground cover at Pawnee 17 than Pawnee 27 (which had a fine clay loam soil) also supports the notion of greater water availability.

As is common for most disturbed areas (Langer & Arbogast, 2002), the PLC site contained higher amounts of invasive weeds than the Pawnee Grassland sites. In particular, high levels of *Convolvulus arvensis* and *Bromus tectorum* contributed to the decreased quality of the site. Noxious invasive plants such as these grow well in harsh abiotic conditions such as poor nutrient soils and low soil moisture, and can propagate rapidly to take advantage of disturbed areas (Grime, 1977). In a gravel mined site, many of the native seeds in the seed bank are removed or buried under overburden. This creates an opportunity for prolific seed producing noxious weeds, such as *Convolvulus arvensis* and *Bromus tectorum*, to colonize. Greater densities of noxious weeds render an increase in propagule pressure which ensures continued presence of these noxious weeds. Noxious weeds may also compete effectively against native plants, preventing them from becoming established. Prior studies predict that functionally similar natives will compete more effectively than plants that are functionally dissimilar (Pokorny et al., 2005; Emery, 2007), although it is unknown how functionally equivalent native plants extirpated from the PLC would compete with the invading noxious weeds. From a management perspective, some of the native functionally equivalent plants may require the direct input of seeds. In addition, in an arid environment such as the shortgrass steppe, once established, perennial warm season grasses are expected to compete effectively against invasive weeds as demonstrated in a previous study (Ang et al., 1995).

Many measures of restoration success compare the diversity of the restoration site to a reference site (Martin et al., 2005; Ruiz-Jaen & Aide, 2005). It is a generally accepted concept that the greater the diversity of a site, the greater the resilience and stability of an ecosystem (Tilman, 1996). Hypothesis 2, "Species diversity of reference sites is greater than the PLC," was accepted. The lower level of diversity at the PLC compared to the Pawnee sites could be due to the relatively short period of time since the termination of mining or due to constraints placed on plant growth because of the residual abiotic conditions caused by gravel mining. Studies have shown plants colonizing mine sites from distances greater than 10 km but this colonization process takes time (Kirmer et al., 2008) and as decades pass after the termination of mining, species diversity increases (Rehounkova & Prach, 2010). If the lack of diversity was caused by the short recovery period, diversity may increase naturally over time as succession continues and more species colonize the site. If the decreased diversity was caused by the abiotic conditions of the site, altering soil phosphorus and potassium levels should equalize PLC soil conditions and reference conditions.

Hypothesis 3, " Biomass of reference sites is significantly greater than the PLC," was accepted. The reference sites exhibited greater biomass than the PLC. The lower levels of above-ground and below-ground biomass observed at the PLC are likely due to the recent establishment of plants after the gravel mining and the types of plants becoming established. One of the dominant plants identified at the PLC is the grass *Bromus tectorum*. Because of the annual growth habit of this plant, little above-ground or below-ground biomass is developed. The higher shoot-to-root ratio at the PLC can also be attributed to the presence of more annuals similar to a previous study (Schenk & Jackson, 2002). Perennial warm season grasses often have well established root systems that exceed their above-ground structure (Weaver, 1968). This growth strategy, characterized by many of the native plants of the shortgrass steppe, allows them to store vast quantities of energy in their root systems that can be utilized when conditions become favorable. Grazing may also shift the ratio of shoot biomass to root biomass (Christiansen & Svejcar, 1988). Above ground biomass was less at the PLC and significantly different from Pawnee 27, although the amount of above ground biomass at the PLC was not significantly different from Pawnee 17. It is likely that Pawnee 27 was different from the PLC because of the noticeable impact grazing had on this site (personal observation) heavy grazing has been shown to decrease above ground biomass (Van Der Maarel & Titlyanova, 1989). For the soil litter measurements, the PLC generally showed greater amounts of litter compared to Pawnee Grassland sites. Again, this is probably due to the increased impact of grazing on both Pawnee sites.

The PLC sites themselves differed significantly from each other in terms of rockiness and both above and below ground biomass. The higher amounts of biomass for the southern area could be partially due to the recent impacts the site has experienced through flooding. The northern plots were under water in the spring of the 2010 contributing to their decreased aboveground biomass, flooding has been shown to decrease biomass (Van Eck et al., 2004). Another possibility explaining the differences is that the north plots appeared to have been more dramatically impacted by mining and therefore has taken longer to become established. As disturbance intensity increases, time to recovery becomes longer as demonstrated previously (Coffin et al., 1998).

Hypothesis 4, "Soil characteristics of reference sites are significantly different from the PLC," was accepted. Soil characteristics were different between the PLC and reference sites. The higher calcium levels at the PLC may explain the significantly higher pH of the PLC site. Higher calcium levels contribute to increases in pH (Bradshaw et al., 1960). The lower amount of soil organic matter and estimated nitrogen release for the PLC could be because of the recent exposure of subsurface soil to the surface through the gravel mine process. A decrease in these variables at mine sites was noted from previous studies (Indorante et al., 1981; Banning et al., 2008). The lower amount of phosphorus and potassium at the PLC could be acting as a limiting factor for plant growth, as both phosphorus and potassium are critical plant nutrients (Donahue et al., 1977). The higher calcium and magnesium levels at the PLC also contribute to the increased alkalinity of this site and make the site more conducive to plants tolerating high alkalinity; e.g., *Sporobolus airoides*. The increased pH impacts nutrient availability for plants; in particular the macronutrient phosphorus and the micronutrient iron are decreased as noted from prior research (Brown 1978, Hinsinger 2001). The amount of organic matter will increase as the soil matures and more surface litter gets incorporated into the soil (Frouz et al., 2008).

Hypothesis 5, "Functional group composition of reference sites are significantly different from the PLC," was accepted. MRPP results showed the PLC being different from reference sites. Although, a community similarity analysis utilizing functional groupings showed greater site similarity functionally than when looking at species composition. The PLC has greater amounts of annual grasses and lacks many of the forbs found on the Pawnee sites. Since no forbs were included in the re-vegetation effort, this could explain the lower number of forbs present on the site. Including forbs in future replanting efforts could shift the forb composition toward greater abundance (Martin & Wilsey, 2006). In particular, including a nitrogen fixing plant such as *Sophora nuttalliana*, which was found at both Pawnee sites, could increase the availablility of nitrogen in the soil (Bradshaw, 1997). This increase in forbs would also increase the diversity of the PLC site.

Hypothesis 6, "Heterogeneity of reference sites are significantly less than the PLC," was rejected. The structure of the PLC is similar to the reference sites based on the coefficient of variation for biomass, indicating the heterogeneous distribution of vegetation is similar.

There were a few limitations to the study. One of the limitations is in the selection of the references sites. As noted previously these sites were selected based on soil characteristics and location within riparian areas but, it is possible that they do not correctly represent functionally intact areas of the shortgrass steppe. The sites selected may themselves degraded due to cattle grazing. Another limitation to the study was lack of replicates of the experimental sites. This limitation was intentiaonal as the study was assessing specific reclamation procedures utilized at the site, but does limit the transferability of the results to other gravel mine sites on the shortgrass steppe. In addition, taking ground cover measurements during peak biomass likely excluded some of the early spring species.

Assessment of Restoration Success

Of the nine recommended restoration attributes (SER 2004; Table 9), three of the attributes at the PLC showed significant differences compared to Pawnee reference sites: species composition, functional group dominance, and the physical environment. Completely reclaimed sites should have similar species as reference sites. In addition, they should be composed of similar functional groups which will enable continued ecosystem progress toward a restored end point. Further, the restored site should have a physical environment capable of providing required resources for continued development (SER 2004).

Restored sites should also show a high percentage of native species, but this study found lower amounts of native species (59.1%) at the PLC than the Pawnees sites. Pawnee site 27 had 91.8% of the species being native and Pawnee site 17 had 73.3%. The community similarity analysis showed that species composition was more varied than functional groups, indicating that functionally the PLC is similar to the Pawnee grasslands; indeed, functional composition of the PLC was more similar to the reference sites than the two reference sites were to each other.

Table 9. Nine parameters recommended by the society of ecological restoration. The ↓ symbol indicates the site has lower values for the variable, the = symbol indicates similar values for the variables, the ≠ symbol indicated not similar values for the variable, and the ↓↑ symbol indicates lower values for some of the variables and higher for others.

SER Measurement for Restoration Success	Measurement parameters	PLC vs. Pawnee 17	PLC vs. Pawnee 27	Pawnee 17 vs. Pawnee 27
Similar diversity of and community structure as reference sites	diversity indices	↓	↓	↑
	community similarity analysis with species	≠	≠	≠
	coefficient of variation for biomass	=	=	=
	MRPP, indicator species analysis	≠	≠	≠
Presence of indigenous species	% natives of total species	↓	↓	↑
Presence of functional groups needed for long-term stability	community similarity analysis with functional grouping	= (>50% similar)	=(>50% similar)	=(>50% similar)
	MRPP, with functional types	≠	≠	≠
Capacity of the of the physical environment to sustain reproducing populations	soil characteristics comparison	↓↑	↓↑	↓↑
Normal functioning	community similarity analysis with functional grouping	= (>50% similar)	=(>50% similar)	=(>50% similar)
Integration with landscape	not directly measured	=	=	=
Elimination of potential threats	not directly measured	↓	↓	=
Resilience to natural disturbances	not directly measured	=	=	=
Self sustainability	not directly measured	=	=	=

The following attributes appear to be met with the PLC but were either not directly measured in this study or lacked baseline studies to assess the attributes. The function of the PLC appears to be at the level for a community at its stage of development (Munson & Lauenroth, 2011) and has also been integrated into the broader ecological matrix. Evidence of this claim comes from the fact that replanting efforts have not been required at the PLC. The PLC likely continues to be impacted via threats from surrounding degraded landscapes as gravel mining continues in close proximity to the site. In addition, it is expected the direction of ground water flow has changed due to the bentonite slurry wall lining the lake created from the gravel extraction (unpublished data from the PLC corroborate the altered ground flow). It appears that the PLC is self sustainable and also has built up a level of resilience to normal stresses. This self sustainability can be seen by the continued increase in ground cover on the site (personal observations) and resiliency has been demonstrated by the fairly rapid response and resiliency of regions of the PLC to flooding in 2009 and 2010 (personal observations).

Future Studies

It is recommended that continual monitoring be conducted on the PLC site to gain an understanding of how a gravel mine site on the shortgrass steppe progress in response to reclamation. This monitoring could help verify successional models (Munson & Lauenroth, 2011).

A study establishing research sites with input of potassium and phosphorus could determine how limiting these variables are in plant growth and species composition of the site. Although, a previous study showed that the noxious weed *Bromus tectorum* increased with this treatment in the foothills of Colorado (Cherwin et al., 2009). In addition, active planting of native forbs including legumes could change the structural composition of the vegetation of the PLC and the mineral composition of the soil.

Another question is the impact grazing has on vegetation patterns on the shortgrass steppe. Are the differences in shoot to root ratios and species composition due to cattle grazing? A grazing study could be set up at the PLC or similar site. Increased grazing could shift the vegetation at the PLC more toward perennial warm season grasses and increase the amount of root biomass compared to the aboveground biomass (Van Der Maarel & Titlyanova, 1989).

Management Recommendations

Although the PLC cannot be considered completely reclaimed compared to the Pawnee reference sites, much progress has been made toward a sustainable functioning ecosystem. The management procedures, including planting of the native seed mix and control of noxious weeds, appear to have been successful in restoring the PLC toward the reference sites on the shortgrass steppe.

It is likely that the end point of reclamation of the PLC will be slightly different from the reference sites based on current species composition and soil characteristics, but the results of this study are encouraging. Dramatic progress can be seen based on the high percentage of ground cover at the PLC and a species composition consisting of native perennial grasses.

Increasing the nutrients by adding phosphorus and potassium to the PLC site would be possible, but because much of the calcium is present in the form of free lime (personal observation), little can be done to lower the pH. Rather, plants being utilized for reclamation should be tolerant of the increased pH of the site. Planting more native forbs should increase species diversity, and it is also recommended that measures to control noxious weeds are continued. Incorporating these management suggestions should bring the PLC closer to the biotic and abiotic conditions of the reference sites.

CHAPTER III

RESPONSE OF RIPARIAN/LOWLAND AREAS OF THE SHORTGRASS STEPPE TO THE RELEASE FROM CATTLE GRAZING USING EXCLOSURES: COMPARISON OF DIFFERENT SPATIAL AND TEMPORAL SCALES

Abstract

Human impact on grassland areas through cattle grazing has had a profound influence on plant structure and composition in these areas, but little research has been conducted investigating grazing impact on riparian areas of the shortgrass steppe. A one grazing season and a multi-year study were conducted to address this issue. Species composition and functional composition were compared for areas exposed to grazing and areas released from grazing. In addition, soil nutrient levels and biomass levels were compared over one grazing season. Results from the single grazing season study showed areas exposed to grazing had less aboveground biomass and greater heterogeneity than non-grazed areas. The multi-year study showed that species composition varied comparing grazed to un-grazed areas from the onset, but demonstrated similar decreases and increases for diversity and species composition. This suggested other environmental factors, perhaps hail, had a greater impact on the system than grazing. Release from grazing caused the system to change more than continual grazing and resulted in increased species evenness. Functional composition started and remained different for

the treatments but within treatments did not change significantly. This study demonstrates variability of species composition from year to year on the shortgrass steppe and supports the concept that grazing has minimal impact in regions adapted to low levels of precipitation.

Introduction

Understanding the impact of grazing on different grassland communities has contributed to our knowledge of ecosystem dynamics under this selective pressure (Milchunas et al., 1988b; Anderson & Briske, 1995; Olff & Ritchiee, 1998; Adler et al., 2004; Derner & Whitman, 2009) and has ensured continued sustainable cattle production. Studies have been conducted on the shortgrass steppe investigating the impact of grazing (Milchunas & Lauenroth, 1989; Hazlett, 1992 ; Milchunas et al., 1994; Hart & Ashby, 1998; Hart, 2001; LeCain et al., 2002) but none of these studies investigated specifically the impact of release from grazing on community structure and dynamics in riparian areas. Considering the uniqueness of riparian areas on the shortgrass steppe (e.g., greater diversity, (Stohlgren et al., 1998)), grazing response in riparian communities may be different than upland communities.

The shortgrass steppe is a unique ecosystem characterized by low levels of precipitation (260-375 mm; Anderson, 2006) and large and rapid temperature changes (Pielke & Doesken, 2008). It is impacted by the low level of precipitation in general and periodic drought more directly. This semiarid environment is unique compared to other grasslands and shows different responses to disturbances (Stapp et al., 2008). The low levels of precipitation contribute to an ecosystem dominated by grasses; specifically, shortgrass steppe in Colorado is characterized by short monostructure grasses composed of blue grama (*Bouteloua gracilis*) and buffalo grass (*Bouteloua dactyloides*) (Lauenroth, 2008). Both are perennial warm season (C_4) grasses. Another impact of periodic droughts is the small number of shrubs present in this environment, which include saltbush (*Atriplex canesens*), rabbit bush (*Chrysothamnus nauseosus*), plains prickly pear cactus (*Opuntia polyanthemos*), and soapweed yucca (*Yucca glauca)*. Low precipitation levels make the shortgrass steppe less resilient (the amount of time needed to return a system to pre-disturbance levels; Ives, 1995) and resistant (ability to absorb changes through time; Sutherland, 1974) to intense anthropogenic disturbances. Because the shortgrass steppe is characterized by low levels of precipitation, large rivers are uncommon, but there are creeks and ephemeral stream beds (Singh et al., 1996) which occur more frequently. These riparian areas were important to early settlers and are important for native wildlife (Hazlett, 1998). On the shortgrass steppe, riparian areas also provide unique habitat for many native and exotic plants (Stohlgren et al., 1998; Schiebout et al., 2008).

Ungulate grazing historically had a profound influence on shortgrass steppe vegetative structure (Larson, 1940; Milchunas et al., 1988a) and continues to impact plant structure and function through domestic cattle grazing (Milchunas & Lauenroth, 1993). Some studies suggest that moderate levels of cattle grazing can have beneficial effects on many grass species through the promotion of an increase in productivity (McNaughton, 1993); other studies highlight the negative impacts of ungulate herbivores on arid ecosystems including the removal of certain plants, redistribution of seeds and nitrogen, and compaction of soil (Blensky & Blumenthal, 1997). Studies looking at heavy cattle grazing have shown that grazing increases basal cover of grasses and decreases basal cover of forbs (Milchunas et al., 1988a). In addition, heavy grazing on restored mixed grass prairie soils has been shown to reduce the rate of soil nutrient and organic matter accumulation as well as increase the amount of bare ground (Fuhlendorf et al., 2002).

In upland grazed pastures of the shortgrass steppe, areas released from grazing after 56 years showed an increase in cool season grasses and forbs compared to an increased amount of warm season grasses (LeCain et al., 2002). Species richness was higher in moderately grazed pastures compared to ungrazed pastures but no different in lightly grazed pastures (Hart, 2001). Productivity was found to decrease following heavy grazing in years of increased and average precipitation (Milchunas et al., 1994). Biomass (Hart & Ashby, 1998; Hart, 2001) and bare ground were greater in grazed areas and grazed areas accumulated less litter (Hazlett, 1992).

In general, riparian areas throughout the U.S. are negatively impacted by grazing (Hoorman & McCutcheon, 2005). These grazed riparian areas are susceptible to trampling and elimination of vegetation through uprooting (Clary & Webster, 1989). In riparian areas, grazing also decreases vegetative biomass and litter (Kauffmann & Krueger, 1984; Schultz & Leininger, 1990; Giuliano & Homyack, 2004) and contributes to a decrease in species diversity (Lucas et al., 2004). Because of the increased grazing occurring in riparian areas of the shortgrass steppe (Schwartz & Ellis, 1981; Senft et al., 1985), impacts on above-ground vegetation in these areas may be greater than in upland regions. Cattle congregate in lowland areas during the growing season, which amplifies the negative impacts of trampling from heavy grazing (Senft et al., 1985). Although, increased grazing intensities for short periods of time did not significantly alter plant composition in upland areas (Derner & Hart, 2007). Here we investigate the response of riparian areas on the shortgrass steppe after they are released from grazing. This knowledge will enable resource managers to make land use decisions with knowledge of how vegetation patterns in riparian areas of the shortgrass steppe respond to reduced grazing or cessation of grazing.

Specifically, we examined a five-year study of a large cattle exclosure and a one-year study of several meter square cattle exclosures in the Pawnee Grasslands of Colorado. We hypothesized that: (1) vegetation composition and functional group composition of excluded areas will significantly differ from grazed areas, (2) diversity will be greater in exclosures, (3) biomass and maximum height of plants will be greater in the excluded plots following one grazing season, (4) heterogeneity measured by coefficient of variation will be greater in grazed areas, and (5) soil nutrient composition will be significantly different for un-grazed compared to grazed plots.

Methods

Site locations

Research was conducted at the Shortgrass Steppe Long-Term Ecological Research (SGS LTER) site located approximately 40 km north of Greeley, Colorado. The SGS LTER is composed of the USDA ARS Central Plains Experimental Range (CPER) and is part of the larger USDA Forest Service Pawnee National Grassland (PNG) (Lauenroth et al., 2008). The CPER is a continuous 6280 ha block of land (40°49' N latitude, 104 °47'' W longitude) and was established by purchasing land from farmers and ranchers unable to keep their land following the dust storms and drought of the 1930's. Cattle grazing has occurred on the CPER since 1939 (Coffin et al., 1998). The Pawnee National Grassland is composed of 78,100 ha of fragmented public land in a matrix private land holdings. Average yearly precipitation is 321 mm (Lauenroth et al., 2008). Blue grama (*Bouteloua gracilis*) with Buffalo grass (*Buchloe dactyloides*) dominate plant communities of the SGS LTER (Singh et al., 1996).

The two research sites were located in Colorado Township 10N, Range 65W, Section 17 (40˚50'7 N latitude, 104˚41'19" W longitude) and Colorado Township 10N, Range 65W, Section 27 (40˚48'32" N latitude, 104˚45'36" W longitude). These areas were chosen because they represented riparian areas on the shortgrass steppe, being located next to Eastman Creek and Little Owl Creek, respectively (Figure 22). Ephemeral streams like these are located in many arid environments and result in a unique plant structure and composition (Shaw & Cooper, 2008). In addition, both sites have been moderately grazed with section 17 having a grazing density of 0.150 cattle ha^{-1} and section 27 having a grazing density of 0.155 cattle ha^{-1} for the duration. Loamy soils characterize these sites generally and specifically Nunn Clay Loan dominates site located in Section 27 and Avar Fine Clay Loam dominates the site located in Section17 (Crabb, 1982).

Two different studies were conducted to investigate how cessation of grazing impacts riparian areas on the shortgrass steppe. One study investigated impacts over one growing season and utilized ground cover, biomass and soil data as well as tallest species per 1 m^2 plots to compare plots that were grazed vs. plots that were not grazed. The other study, initiated by Gary Fraiser with data collection conducted by the CPER crew, utilized transect data from section 17 to determine shifts in vegetation patterns over a period of five years for areas exclosed from cattle grazing compared to areas exposed to grazing pressure.

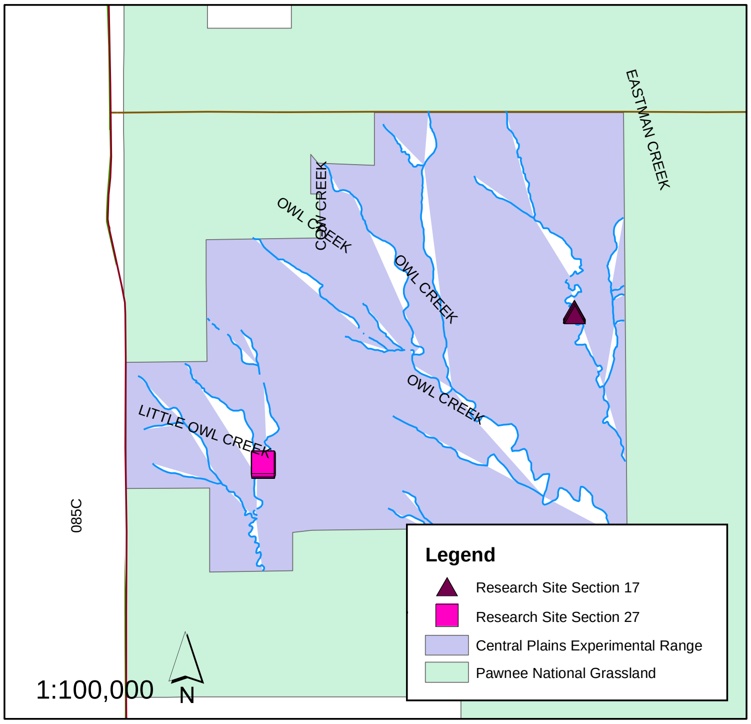


Figure 22. Location of shortgrass steppe riparian research sites on the Pawnee National Grassland. Markers indicate research site 17 located adjacent to Eastman Creek (40˚50’7 N latitude, 104˚41’19” W longitude) and research site 27 adjacent to Little Owl Creek (40˚48’32” N latitude, 104˚45’36” W longitude). Areas were chosen because they represent riparian areas on the shortgrass steppe.

Study 1: One year cessation from grazing study

To investigate annual impact of cattle grazing in riparian areas of the shortgrass steppe, 80 randomly placed 1 m^2 plots were selected prior to annual cattle grazing in the spring of 2010. The 1 m^2 plots were located in two riparian regions as mentioned above and were situated at least 2 m apart from each other to maintain independence. From these 80 randomly placed plots, 20 plots were randomly selected from each area and were covered by approximately 1 m^3 cages constructed from cattle panels and mesh (Figure 23; Figure 24). These cages were open at the bottom to allow plant growth and functioned to prevent cattle and other mammal herbivory but not insect herbivores. Cages have been shown alter microclimate contributing to an increase in plant production (Owensby, 1969) but the increase noted in Owensby (1969) in plant production would be insignificant over the 1 m^2 plots used in our experiment.

Figure 23. Exclosure cage used to cover m^2 plots.

Figure 24. Arrangement of cages in Section 27, shortgrass steppe Colorado. Photo taken toward the end of the growing season, 2010.

To test the hypothesis that grazing affects vegetation cover and composition, overall averages for vegetative cover, amount of bare ground, amount of cow dung, and amount of litter present were determined for the caged/non-grazed and the grazed plots. A MANOVA was run after log transformation of data to determine significant differences in cover. The software program PC-ORD 5.10 was utilized to determine if sites were similar to each other based on community composition. A nonmetric multidimensional (NMS) ordination was performed utilizing the percent cover data for each plot. Specific parameters for this test included a Sorensen (Bray-Curtis) distance measure with 50 runs and two axes; the stability criterion was set at 0.00001 with 15 iterations. The maximum number of iterations was set at 100 with step down in dimensionality. The initial step length was 0.20 with random numbers serving as the source (100 randomizations). To statistically verify the visual differences observed from the ordination, a multi-response permutation procedure (MRPP) analysis was performed using the same distance measure.

To test if grazing affects maximum height of plants and biomass in caged vs. non-caged plots, maximum height of the tallest plant in each cage was recorded during peak biomass (July 20-24, 2010), and a paired t-test was used to determine if there was a significant difference. In addition, above-ground and below-ground biomass data were collected utilizing an 8 cm diameter, 18 cm tall (0.9 liter) soil sampling auger with three collection locations per plot. Any plant material located above the cylinder was collected as above-ground biomass while below-ground biomass was collected from root structure of the soil collected in the auger. Root structure and litter were separated from soil using a 2 mm sieve in the lab. Above and below-ground biomass and litter samples were dried at 75 °C in a drying oven for 48 hours prior to being massed. A blocked (by site) design MANOVA was run followed by a blocked design ANOVA with mean differences being determined by a *post-hoc* Student Newman Kuels test. Because there were three data points for biomass from each plot, an examination of variability as a proxy for heterogeneity was possible to test the heterogeneity of vegetation biomass. To test for such heterogeneity, a coefficient of variation (standard deviation/mean) was calculated for each plot for above ground biomass, belowground biomass, and litter. Calculated values were then analyzed using an ANOVA after the data were log transformed.

After the belowground biomass, litter and rocks were removed from the soil, the three soil samples from each plot were combined. Ten plots from each site were randomly chosen and soils from these plots were sent to A & L Laboratories Inc. for analysis of estimated nitrogen release (ENR), pH, Ca, Mg, K, P and soil organic matter (SOM). A blocked design MANOVA was run to determine if differences existed for soil composition; data were log transformed.

Species composition data utilizing abundance and frequency (Bonham, 1989) were analyzed to determine if cattle preferentially chose certain plants over others. Interpretation of the Species Indicator Analysis was based on a strong, moderate and weak indicator criterion with strong indicators having a value > 50%, moderate species having values between 25-50% and weak species having a value of < 25% with a cutoff at 5%. A Monte Carlo test of significance was run to determine if the observed indicator value was significant. To further investigate this question of forage preference, the five most abundant tallest plants found in the grazed and un-grazed plots were compared.

Study 2: Five year transect study

To determine if changes in community composition occurred with longer-term cessation of grazing, data were analyzed from a five year study initiated by Gary Frasier (USDA). This study involved fencing off 10.1 hectares of previously grazed riparian rangeland. Vegetation data were collected over a five-year period: 1995, 1997, 1998 and 1999. Twelve transects were placed perpendicular across a riparian area in section 17 (40˚50'7 N latitude, 104˚41'19" W longitude) from upland to upland (Figure 25). Six of the twelve transects were fenced to prevent cattle grazing prior to the 1995 grazing season (Figure 26). Vegetation composition was evaluated across these transects utilizing the point drop intersect method by the CPER staff (Figure 27) from mid July to early August. Measurements were recorded 25 or 26 times along each transect for a total of 250 or 260 ground cover measurements (species, litter or bare) being recorded for each transect. These measurements recorded from the point drop method were converted into % cover. Conservatively, three *Poa* species were combined (*Poa arida*, *Poa pratensis*, and *Poa secunda*) and two *Carex* species (*Carex* sp. and *Carex stenophylla*) were combined for analysis because species identification was tentative (Ashby personal communication). Because all of the *Poa* species occupy lowland, moist areas on the steppe (USDA Forest Service, 1988), combining these species did not compromise ecological relationships. Data were not recorded for 1996 because a severe hail storm decimated the study site making species identification difficult (Ashby personal communication).

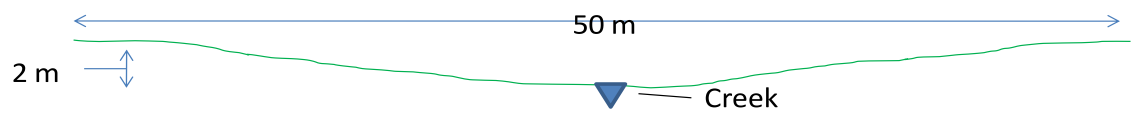


Figure 25. Orientation of the transect perpendicular to the lowland area from upland to upland; an ephemeral creek is located in low lying region of the transect.

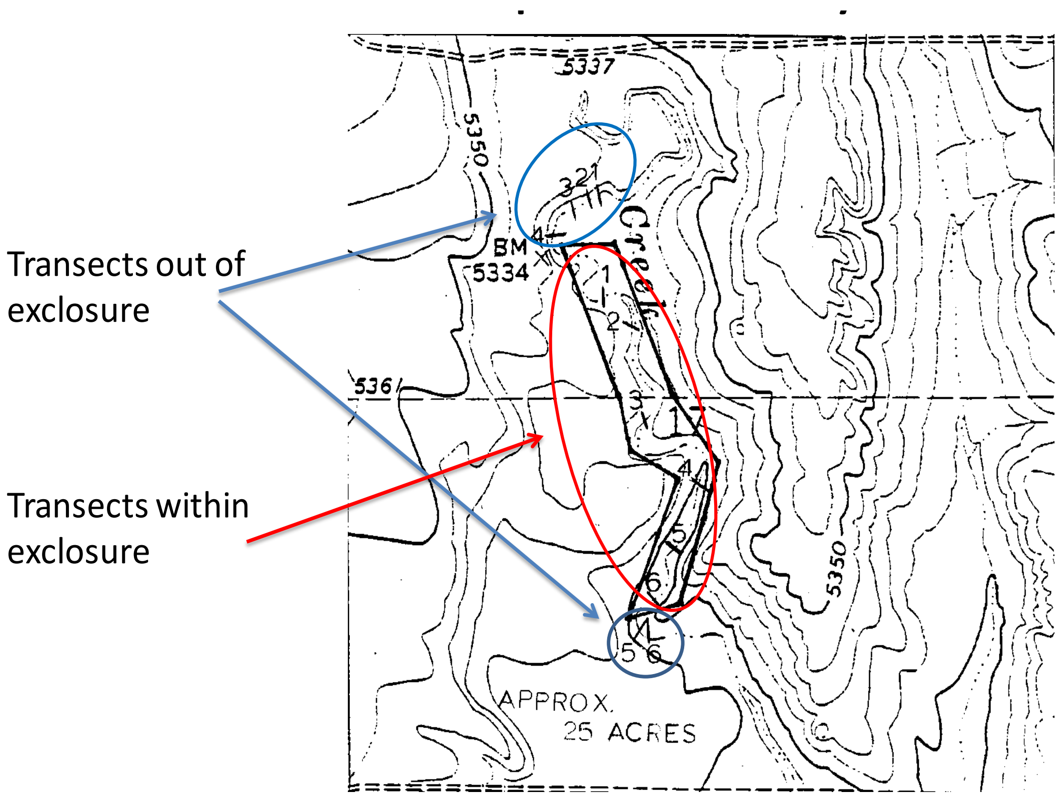


Figure 26. Location of the transects in the exclosure (un-grazed; red circle) and six transects exposed to continuous grazing (blue circles).

Figure 27. Point drop method for determining species composition for the five-year transect study, Pawnee National Grassland, CO. Photo courtesy of CPER staff.

To test if composition shifts occurred in cattle exclosures, species composition was assessed for all years and the software program PC-ORD 5.10 was utilized to determine if sites were similar. A nonmetric multidimensional (NMS) ordination was performed utilizing the percent composition data including measurements of bare and litter for each transect. In addition, an NMS was performed for just species composition. To better visualize the directional change in composition for each year, average NMS coordinates were determined and plotted. The specific parameters for the NMS test included a Sorensen (Bray-Curtis) distance measure with 50 runs with the real data; the stability criterion was set at 0.00001 with 15 iterations to determine stability. The maximum number of iterations was set at 100 with step down in dimensionality. The initial step length was 0.20 with random numbers serving as the source. One hundred randomized runs were conducted. The seed number used to generate the random numbers was 5316.

To statistically verify the visual differences observed from the ordination, a multi-response permutation procedure (MRPP) analysis was performed. The parameters used for the MRPP included using Sorensen (Bray-Curtis) as the distance measure and the weighing formula being: n/sum(n). The MRPP procedure was conducted comparing treatments as well as comparing possible changes within treatments over time. Paired t-tests were conducted comparing percent of litter in 95 to percent litter in 99 for both treatments to determine if changes observed in the NMS was due to changes in litter or bare cover over time.

Species composition was also investigated utilizing abundance and frequency (Bonham, 1989) measurements calculated from species composition for each transect. From these measurements, a Species Indicator Analysis (McCune & Metford, 2006) was performed between exclosures (non-grazed) and grazed transects for species composition in 1995 and for species compositionin 1999. A Monte Carlo test of significance was run to determine if the observed indicator values were significant. Differences between these indicator species were used to determine how the exclosure species composition changed over a five-year period compared to grazed areas. Interpretation of the analysis was as above. In addition, a comparison of the change in total percent species composition was used to determine if a similar change in species composition occurred within the exclosure and in grazed areas from 1995 to 1999.

To compare sites in terms of species diversity (hypothesis 6), richness (number of different species per plot), evenness (Shannon's diversity index/ ln (richness), diversity I (Shannon's diversity index = - sum (Pi*ln(Pi)) where Pi = importance probability in element I relativized by row total), and diversity II (D = Simpson`s diversity index for infinite population = 1 - sum (Pi*Pi) where Pi = importance probability in element i relativized by row total) were determined for each transect (n=6; N=12). Richness, evenness and Diversity II where determined not to be evenly distributed, so these data were log transformed prior to analysis. A repeated measures ANOVA was used to determine significant differences between the exclosures and grazed transects for each year and to determine if the changes occurring from one year to the next varied.

To test grazing effects on ecosystem function between exclosed and grazed sites over the five year period, plant species were categorized into different functional groups. Sites were compared based on functional group composition of plots located at each site. Functional group classifications included annual cold season (C_3) graminoids, annual warm season (C_4) graminiods, perennial cold season graminiods (C_3), perennial warm season graminoids (C_4), annual forbs, perennial forbs, and perennial shrubs (see Appendix C). The dominance of these functional groups was explored between transects and years using NMS ordination. A MRPP analysis was used to determined if treatments where significantly different from each other in terms of functional groupings. Following this analysis, characteristic functional groups were examined by an indicator species analysis (McCune & Metford, 2006). Interpretation of the analysis was as above. A Monte Carlo test of significance was run to determine if the observed maximum indicator value for each functional group was significant.

Results

One year cessation from grazing study

Caged vs. grazed plots did not significantly differ from each other in terms of cover, litter, bare ground or cow dung (Figure 28; MANOVA: F-value = 1.10, p = 0.425). A Nonmetric multidimensional (NMS) ordination elucidated no species composition differences between the caged and un-caged plots (Figure 29), and that was support by the MRPP (T-value = -0.30, p = 0.29, observed delta = 0.722, expected delta = 0.722). Species diversity, richness and evenness were not significantly different (MANOVA: F-value = 0.93, p = 0.496).

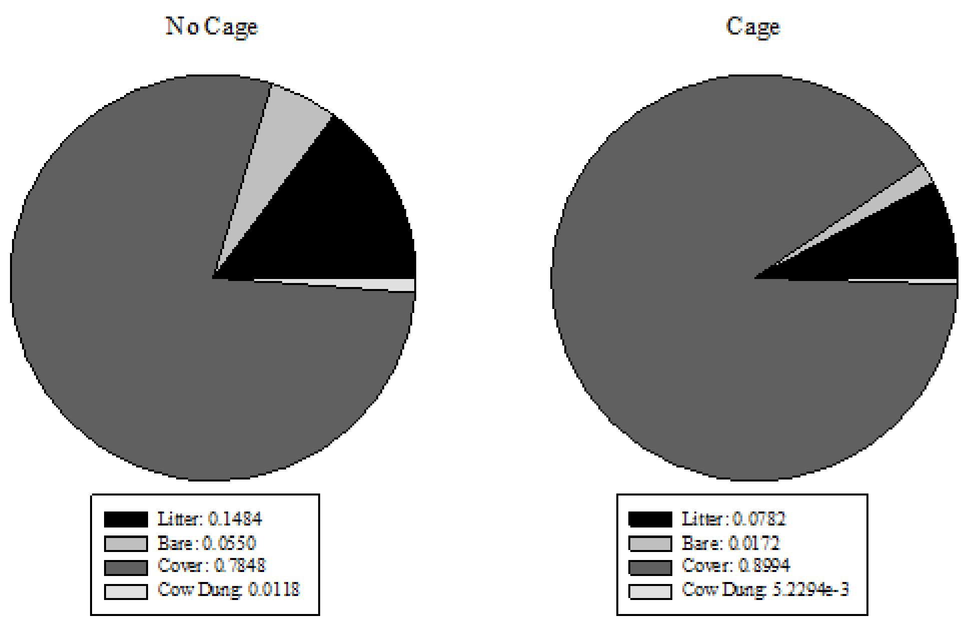


Figure 28. Average composition of cover including bare, litter and cow dung for areas excluded from grazing (cage) and areas exposed to grazing (no cage).

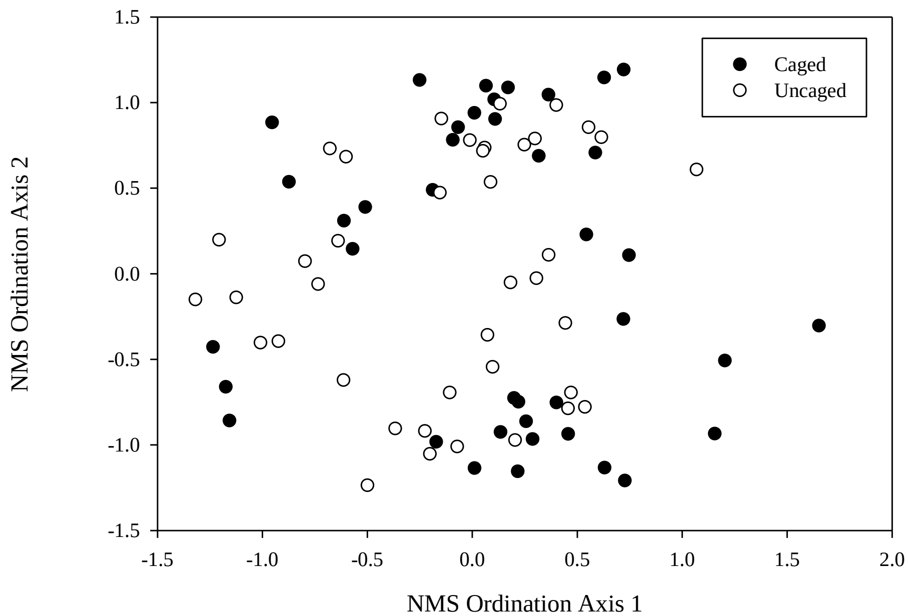


Figure 29. NMS ordination comparing caged (un-grazed) m^2 plots to uncaged (grazed) m^2 plots, Pawnee National Grassland, CO.

Indicator species analysis only showed one species to be significantly different; *Poa segunda* was more prominent in areas excluded from grazing. A few other species were found either in grazed or non-grazed plots. Grazed plots were characterized by *Bouteloua gracilis*, *w*hile non-grazed plots were characterized by *Equisetum laevigatum* and *Kochia scoparia* (Table 10).

Significant differences between biomass measurements were identified from the MANOVA ($F = 5.09$ $p = 0.0014$). Specifically, both above ground biomass and shoot/root ratio were significantly greater (Table 11) in the grazed plots (Figure 30; Figure 31). Belowground biomass, litter and amount of rocks did not differ between treatments.

Maximum plant height was significantly greater in the caged plots (T-value = -5.42, $p < 0.0001$) (Figure 32). *Equisetum laevigatum*, *Hesperostipa comata* and *Nessella viridula* were the tallest species found in caged plots while *Carex stenophylla, Descurainia pinnata*, *Ratibida Columnifera* were the tallest species in grazed plots. *Elymus smithii* and *Sporobolus airiodes* were common tallest species in both grazed and un-grazed plots (Figure 33).

Table 10. Indicator species analysis of caged (non-grazed) and un-caged (grazed) sites on the shortgrass steppe, Pawnee National Grasslands, Colorado.

Monte Carlo Test of Significance		Indicator Values	
Species	P- value	Un-caged	Caged
Bouteloua gracilis	0.07	33	6
Equisetum laevigatum	0.06	6	38
Kochia scoparia	0.07	0	14
Poa secunda	0.02	0	23

Table 11. ANOVA results for biomass, rocks, and shoot-root ratio from grazed and un-grazed plots on the shortgrass steppe, Pawnee National Grassland, CO.

Variable	F-Test	P-Value
Above Ground	16.17	<0.0001
Below Ground	0.83	0.3144
Litter	0.39	0.3755
Rocks	0.45	0.3874
Shoot-Root Ratio	12.83	0.0005

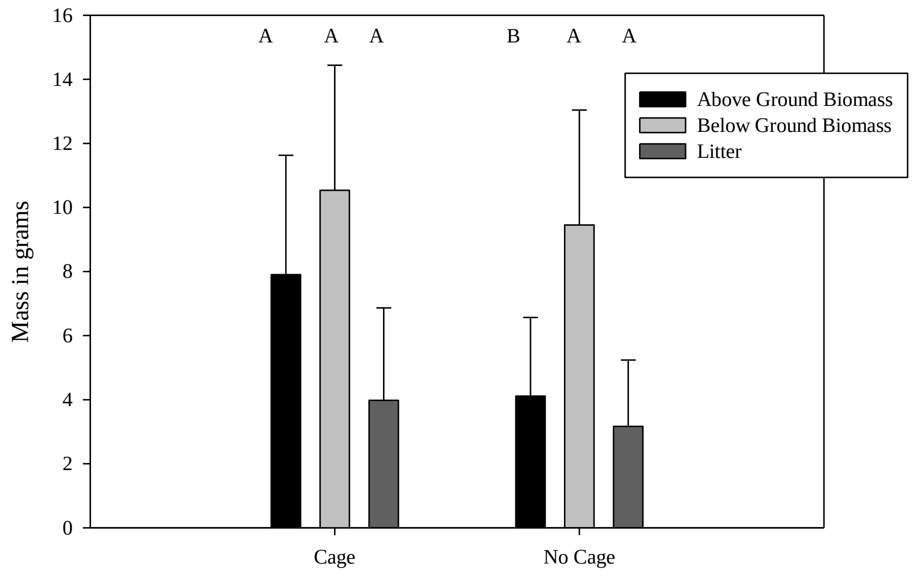


Figure 30. Biomass of caged (un-grazed) compared to un-caged (grazed) m^2 plots on the shortgrass steppe, Pawnee National Grassland, CO.

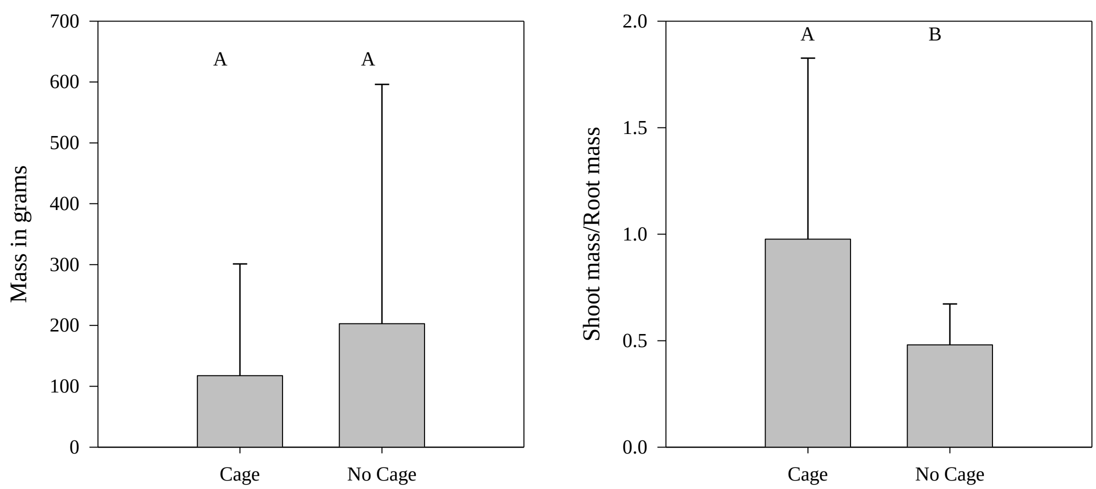


Figure 31. Rock mass and shoot-to-root ratio in caged (un-grazed) compared to uncaged (grazed) m^2 plots on the shortgrass steppe, Pawnee National Grassland, CO.

Soil data comparing estimated nitrogen release (ENR), pH, Ca, Mg, K, P and organic matter (SOM) were not significantly different (MANOVA $F = 0.58$, $p = 0.7828$). In addition richness, evenness, and diversity did not differ between grazed and ungrazed plots (F-value = 1.23, $p = 0.3035$).

Coefficient of variation measurements for rocks, litter, belowground and above ground biomass were not significantly different between treatments (MANOVA $F = 2.29$, $p = 0.0658$). Because of the fairly low p-value, an ANOVA was run to determine if any one variable was significantly different. Above ground biomass was determined to be significantly more variable ($F = 5.24$, $p = 0.0279$) in grazed plots (no cage), indicating more patchiness.

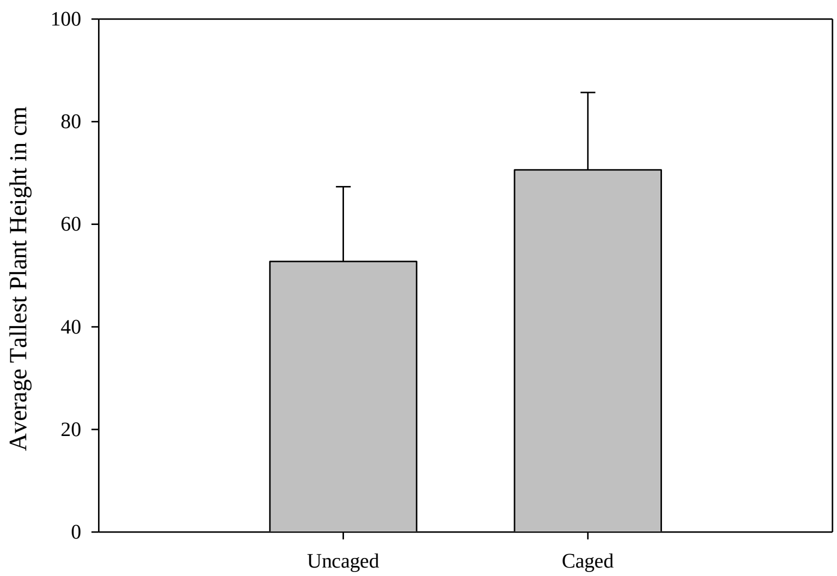


Figure 32. Average height of the tallest plant species located in either grazed (un-caged) plots or un-grazed (caged) plots, Pawnee National Grasslands, CO.

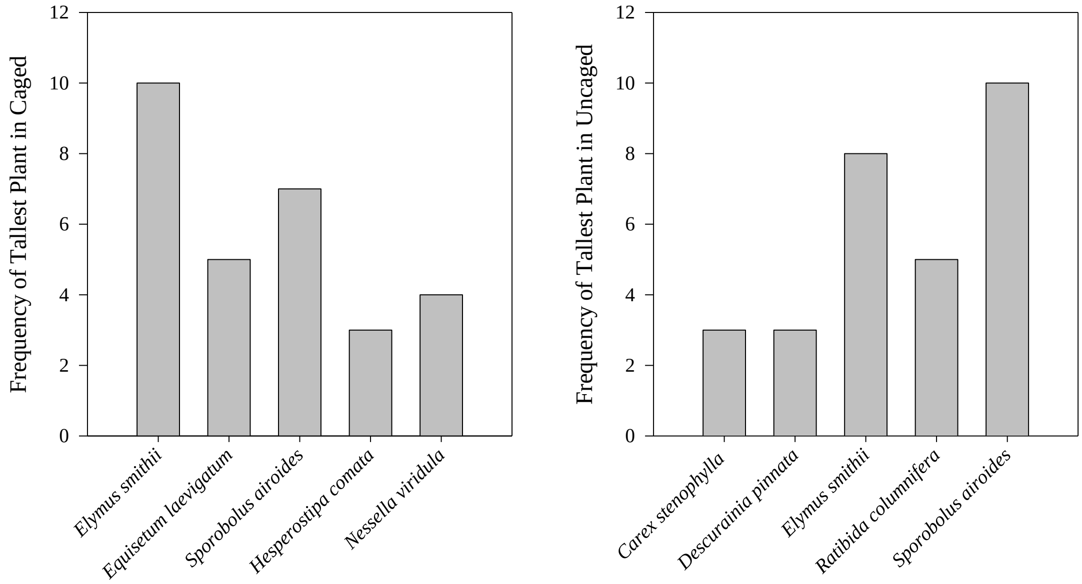


Figure 33. Frequency of tallest plants in un-grazed (caged) and grazed (un-caged) plots, Pawnee National Grassland, CO.

Five year transect study

Vegetation and structural composition were different for the exclosure transects compared to grazed transects from the initial 1995 recording of data (T-value = -2.580, p = 0.014, observed delta = 0.36, expected delta = 0.39). Non-Metric Multidimensional Scaling Ordination showed distinct groupings for each year (Figure 34). A MRPP (T-value = -12.304, p < 0.0001, observed delta = 0.344, expected delta 0.374; litter and bare were not included in this analysis) found significantly different composition for exclosures and grazed areas continuing over the length of the study. However, the species composition changes appeared to move in the same general direction (Figure 34 and 35). When the variables litter and bare were included in the analysis, greater change was observed within the exclosure (Figure 34) than the grazed transects and a paired T-test indicated significant differences between litter from 1995 to 1999 for the exclosures

(T-value = -4.54 p = 0.01). There was not a significant difference in litter values for the grazed transects from 1995 to 1999 or for the amount of bare for either treatment from 1995 to 1999.

Species indicator analysis showed some species were more abundant in the different treatments for each year. For 1995, *Boutelous gracilis*, *Bouteloua dactyloides*, and *Sporobolus ariodes* was more prominent in grazed plots, while *Descurainia pinnata* and *Poa* spp. were more abundant in the exclosure (Table 12). In 1999, *Elymus smithii* and *Sporobolus airiodes* were more prominent in the grazed areas while *Elymus lanceolatus*, *Lactuca serriola*, *Poa* spp., *Solidago canadensis*, and *Sophora nuttalliana* were more prominent in the exclosure (Table 13).

An MRPP indicated that species composition did not change significantly within the exclosure from 1995 to 1999 (T-value = -0.607, p = 0.241, observed delta 0.391, expected delta 0.397) or in grazed transects from 1995 to 1999 (T-value = -1.19, p = 0.119 observed delta 0.271, expected delta 0.285). However, species indicator analysis determined significant changes in species composition within each treatment over the five year period.

In the exclosure, *Elymus smithii*, *Symphyotrichum falcatum*, *Bouteloua gracilis*, *Deschampsia caespitosa*, *Distichlis stricta* and *Lepidium densiflorum* decreased from 1995 to 1999 while *Elymus lanceolatus* and *Solidago canadensis* increased (Table 14). In areas exposed to continuous grazing, *Bouteloua gracilis*, *Chenopodium leptophyllum* and *Lepidium densiflorum* decreased from 1995 to 1999 while only *Distichlis stricta* increased, being identified as a strong indicator species (Table 15).

Because of the change from 1995 and 1997, species composition was further compared for the exclosure and grazed sites. In the exclosure, significant change in species occurred (T-value = -1.81, p = 0.051). Species indicator analysis determined the exclosure species moved from *Bouteloua gracilis, Cirsium undulatum, Deschampsia caespitosa, Descurainia pinnata*, *Lepidium densiflorum*, and *Symphyotrichum falcatum* being important indicators in 1995 to *Agrostis stolonifera, Koeleria macrantha*, and *Schoenoplectus americanus* being important indicators in 1997 (Table 16).

For grazed areas, a MRPP analysis indicated no significant change in species composition from 1995 to 1997 (T-value = -1.19, p = 0.12), but indicator species analysis did indicate a shift in indicators. In 1995, grazed transects were characterized by *Elymus smithii, Bouteloua gracilis, Chenopodium leptophyllum*, *Lepidium densiflorum,* and *Vulpia octoflora.* By 1997, only *Distichlis stricta* and *Muhlenbergia asperifolia* were indicators (Table 17).

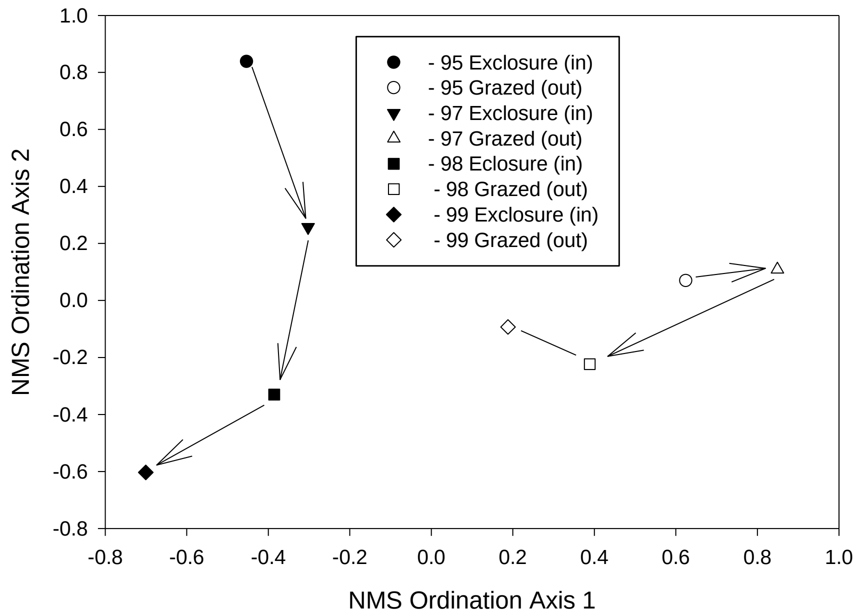


Figure 34. NMS Ordination of average coordinates for each year for the exclosure transects (black) and the grazed transects (clear), Pawnee National Grassland, CO. Included for this analysis were species cover, bare, and litter cover measurements.

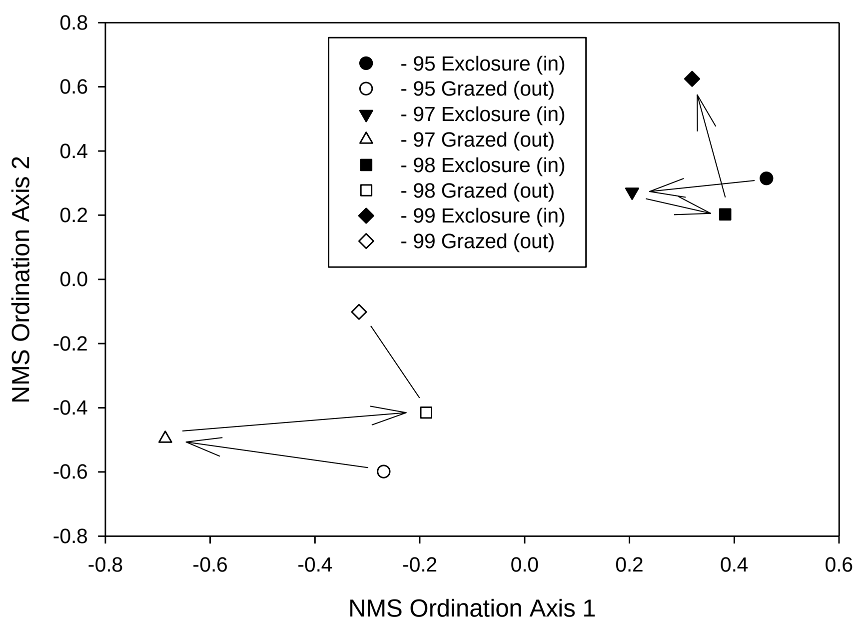


Figure 35. NMS Ordination of average coordinates for each year for the exclosure transects (black) and the grazed transect (clear). Pawnee National Grassland, CO. Included in this analysis was species cover and excluded from this analysis were bare and litter cover measurements .

Table 12. Indicator species analysis of 1995 exclosure (in) and grazed (out) transects on the shortgrass steppe, Pawnee National Grassland, CO.

Monte Carlo test of significance for 95 data		Species Indicator Analysis Indicator Values for 1995	
Species	P value	In	Out
Bouteloua gracilis	0.0808	34	66
Bouteloua dactyloides	0.0606	1	69
Descurainia pinnata	0.0202	93	4
Poa spp.	0.0303	95	1
Sporobolus airoides	0.0808	27	68

Table 13. Indicator species analysis of 1999 exclosure (in) and grazed (out) transects on the shortgrass steppe, Pawnee National Grassland, CO.

Monte Carlo Test of Significance for 99 data		Species Indicator Analysis Indicator Values for 1999	
Species	P value	In	Out
Elymus lanceolatus	0.0707	64	1
Elymus smithii	0.0202	35	65
Lactuca serriola	0.0606	81	1
Poa species	0.0101	98	1
Solidago canadensis	0.0505	67	0
Sophora nuttalliana	0.0404	67	0
Sporobolus airoides	0.0606	39	61

Table 14. Indicator species analysis comparing 1995 to 1999 for exclosure transect data on the shortgrass steppe, Pawnee National Grassland, CO. Arrows indicate either an increase (↑) in the species or a decrease in the species (↓).

Monte Carlo Test of Significance for exclosure data		Species Indicator Analysis Indicator Values		
Species	P-value	1995		1999
Elymus lanceolatus	0.0808	0	↑	67
Elymus smithii	0.0404	69	↓	31
Symphyotrichum falcatum	0.0404	67	↓	0
Bouteloua gracilis	0.0404	61	↓	39
Deschampsia caespitosa	0.0404	67	↓	0
Distichlis stricta	0.0505	68	↓	32
Lepidium densiflorum	0.0808	76	↓	6
Solidago canadensis	0.0707	0	↑	67

Table 15. Indicator species analysis comparing 1995 to 1999 for grazed transect data on the shortgrass steppe, Pawnee National Grassland, CO. Arrows indicate either an increase (↑) or a decrease (↓) in the species composition.

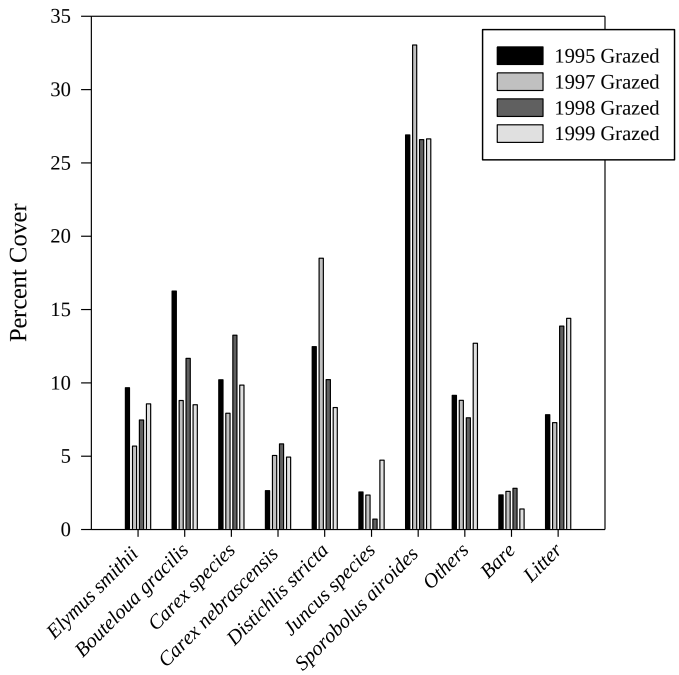
Monte Carlo test of significance for grazed data		Species Indicator Analysis Indicator Values		
Species	P-value	1995		1999
Bouteloua gracilis	0.0909	65	↓	35
Chenopodium leptophyllum	0.0505	75	↓	0
Distichlis stricta	0.0808	40	↑	60
Lepidium densiflorum	0.0303	100	↓	0

Table 16. Indicator species analysis comparing 1995 to 1997 for exclosure transect data on the shortgrass steppe, Pawnee National Grassland, CO. Arrows indicate either an increase (↑) or a decrease (↓) in the species composition.

Monte Carlo Test of Significance for (exclosure)		Species Indicator Analysis Indicator Values		
Species	P-value	1995		1997
Agrostis stolonifera	0.0808	1	↑	61
Symphyotrichum falcatum	0.0808	67	↓	0
Bouteloua gracilis	0.0101	82	↓	15
Cirsium undulatum	0.0808	77	↓	23
Deschampsia caespitosa	0.0808	67	↓	0
Descurainia pinnata	0.0101	100	↓	0
Koeleria macrantha	0.0808	0	↑	67
Lepidium densiflorum	0.0303	83	↓	0
Schoenoplectus americanus	0.0909	22	↑	67

Table 17. Indicator species analysis comparing 1995 to 1997 for grazed transect data on the shortgrass steppe, Pawnee National Grasslands, CO. Arrows indicate either an increase (↑) in the species or a decrease in the species (↓).

Monte Carlo test of significance for grazed data		Species Indicator Analysis Indicator Values		
Species	P value	1995		1997
Elymus smithii	0.0606	63	↓	37
Bouteloua gracilis	0.0303	65	↓	35
Chenopodium leptophyllum	0.0505	75	↓	0
Distichlis stricta	0.0101	40	↑	60
Lepidium densiflorum	0.0101	100	↓	0
Muhlenbergia asperifolia	0.0909	1	↑	64
Vulpia octoflora	0.0707	50	↓	0



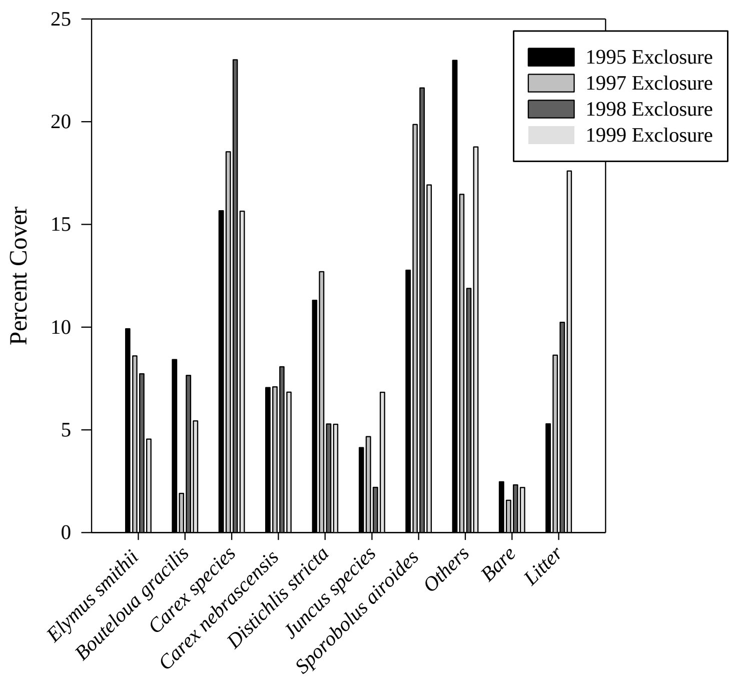


Figure 36. Percent composition of the most abundant species along with litter and bare cover for transects located in the exclosure and grazed areas on the shortgrass steppe, Pawnee National Grassland, CO, for 1995, 1997, 1998 and 1999.

In the exclosure, a continuous increase in litter and a decrease in *Elymus smithii* were observed from 1995 to 1999. For the grazed trasects, an increase in *Elymus smithii* was observed after 1997 as well as a decrease in *Distichilis stricta* (Figure 36).

No significant difference was observed in richness between the exclosures and the grazed areas for any of the years but change from year to year was significant for both treatments (F-value = 67.72, $p < 0.0001$) with a general decreasing trend over the first four years of the study and a significant increase occurring from 1998 to 1999 (F-value = 38.73, $p = 0.0003$). Evenness was only significantly different in 1995 with the exclosure having greater evenness (F-value = 7.55, $p = 0.025$), but it did not significantly change from one year to the next (F-value = 3.47, $p = 0.091$), although a general trend of decreased evenness occurred in the exclosure and an increase in evenness occurred in the grazed transects. Both the Simpson's diversity index (F-value = 6.82, $p = 0.031$) and Shannon's diversity index (F-value = -6.25, $p = 0.037$) showed a significance difference for 1995; the exclosure had greater diversity. Diversity did change significantly over time for both indices (Shannon's, F-value = 24.78, $p = 0.0009$; Simpson's, F-value = 16.89, $p = 0.0025$) with a gradual decline in diversity for the first four years and a significant increase in diversity from 1998 to 1999 within both treatments (Shannon's, F-value = 49.06, $p < 0.0001$; Simpson's, F-value = 21.72, $p = 0.0016$)(Figure 37).

No divergences between the exclosure and grazed areas were seen for richness, evenness, Shannon's diversity index or Simpson's diversity index over time. The changes observed followed similar patterns for grazed and non-grazed transects.
NMS ordination showed functional composition changes over time (Figure 38). Generally, from 1997 on this change was in the same direction for both grazed and

ungrazed areas. An MRPP analysis indicated that functional composition was significantly different for exclosures compared with grazed areas (T-value = -14.91, $p < 0.001$, observed delta 0.173, expected delta 0.220).

There was no significant functional change within the exclosure over the five year period of time (Figure 39) (MRPP comparing species composition in 95 to 99 for exclosure (T-value = 0.561, p = 0.652)) and functional indicator analysis determined only perennial shrubs to have changed significantly from 1995 to 1999 (Table 18, Figure 40).

The NMS ordination indicates change occurred in the exclosure from 1995 to 1997, but an MRPP indicated the overall change was not significant (T-value = -0.277, p = 0.310). Although, functional indicator analysis suggested a significant decrease in forbs from 1995 to 1997 (Table 19), supported as well in the percent ground cover data (Figure 41).

Likewise, grazed transects did not significantly change in terms of functional composition from 1995 to 1999 (T-value -0.762, p = 0.34). Functional indicator analysis indicated no significant differences in functional composition for the study period. But, percent composition did indicate an increase in cold season graminoids and a decrease in warm season graminoids (Figure 40). No significant functional change occurred from 1995 to 1997 either (T-value = 0.18, p = 0.44), and, contrary to the exclosure, no differences in functional composition occurred from 1995 to 1997. Although, a decrease in forbs and an increase in warm season graminoids was observed over the time period (Figure 41).

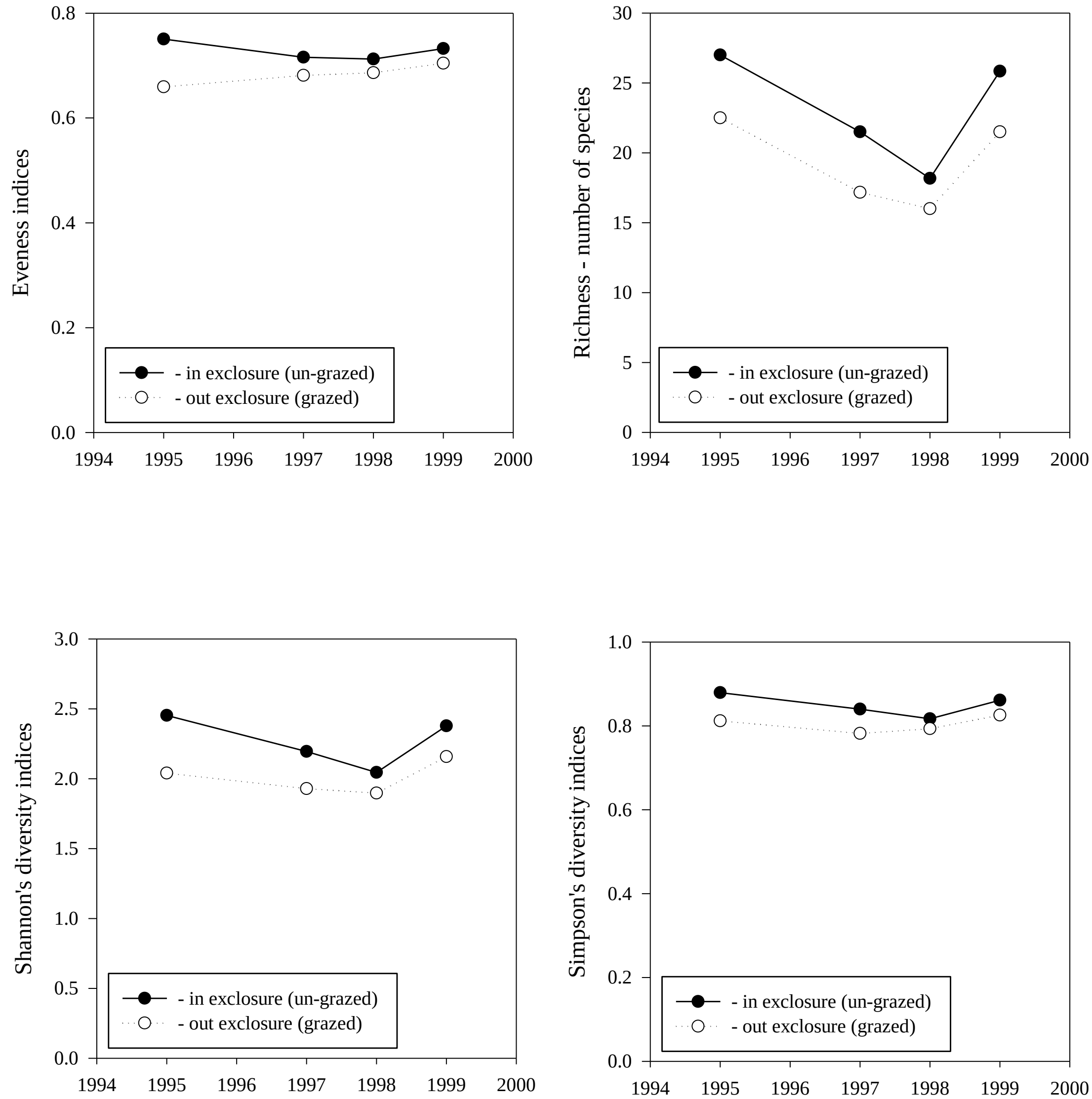


Figure 37. Average evenness, richness and diversity indices (Shannon’s and Simpson’s) for the exclosure and grazed transects on the shortgrass steppe, Pawnee National Grassland, CO, for 1995, 1997, 1998 and 1999.

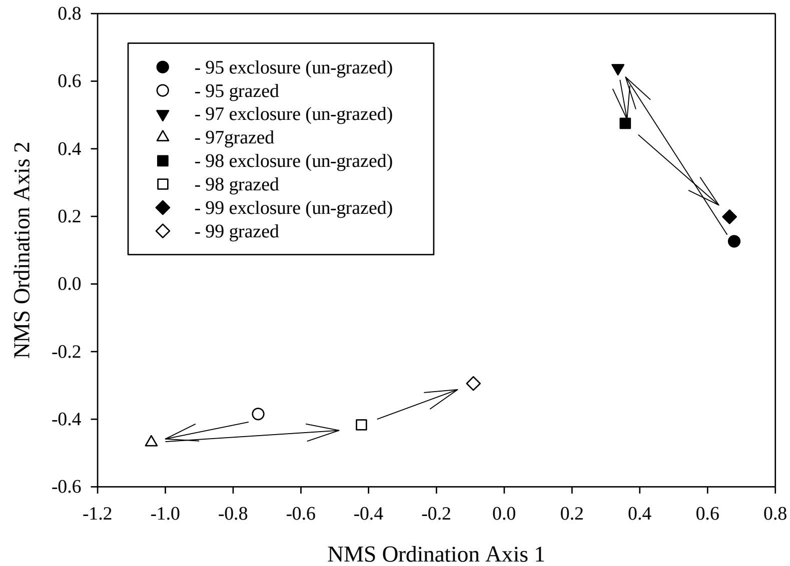


Figure 38. NMS coordinates averaged for functional groupings by treatment and year comparing change through time for exclosure and grazed areas on the shortgrass steppe, Pawnee national Grassland, CO.

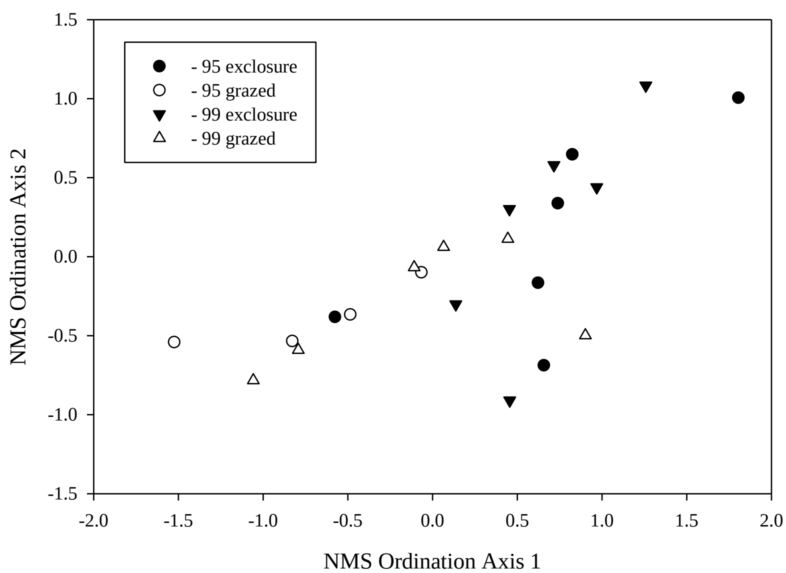


Figure 39. NMS with species organized into functional groupings comparing the exclosure to the grazed areas in 1995 and 1999 on the shortgrass steppe, Pawnee National Grassland, CO.

Table 18. Indicator functional analysis comparing 1995 to 1999 for exclosures on the shortgrass steppe, Pawnee National Grassland, CO.

Monte Carlo Test of Significance for (exclosure) data		Indicator Values	
Species	P-value	1995	1999
Annual Forb	0.2222	70	30
Annual Cold Season Graminoid	0.8889	31	25
Perennial Forb	0.8485	52	48
Perennial Cold Season Graminoid	0.8283	51	49
Perennial Warm Season Graminoid	0.4949	54	46
Perennial Shrub	0.0505	71	2

Table 19. Indicator functional analysis comparing 1995 to 1997 exclosure on the shortgrass steppe, Pawnee National Grassland, CO.

Monte Carlo Test of Significance for in (exclosure) data		Indicator Values	
Species	P-value	1995	1997
Annual Forb	0.0202	81	19
Annual Cold Season Graminoid	0.1919	50	0
Annual Warm Season Grass	0.4747	0	33
Perennial Forb	0.0303	71	29
Perennial Cold Season Graminoid	0.3636	46	54
Perennial Warm Season Graminoid	0.8889	49	51
Perennial Shrub	0.3838	53	24

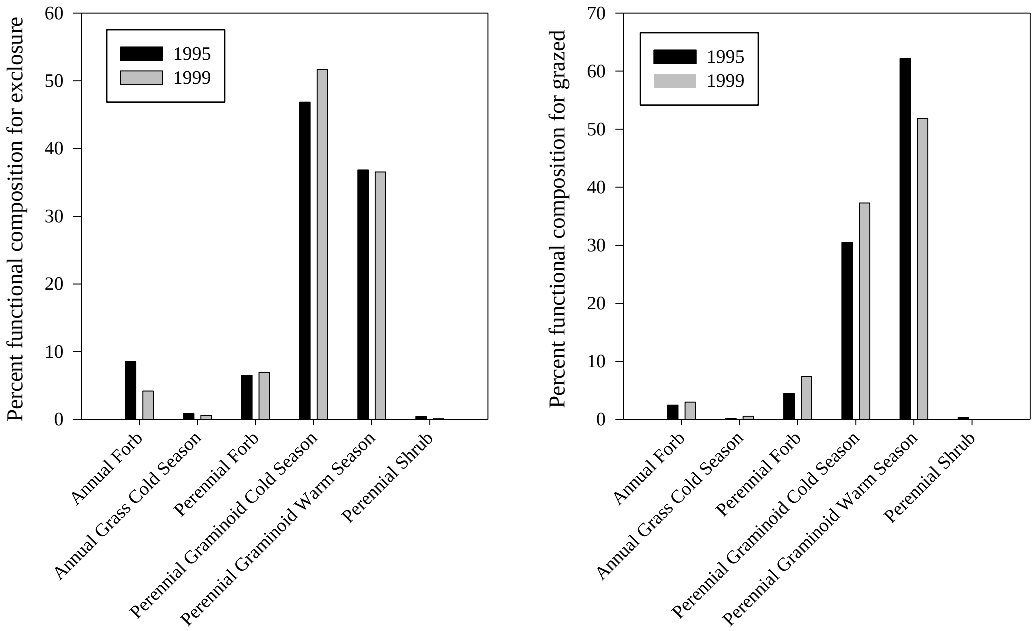


Figure 40. Percentage of functional composition for the grazed transects in 1995 and 1999 and the exclosure (un-grazed) transects in 1995 and 1999, PNG.

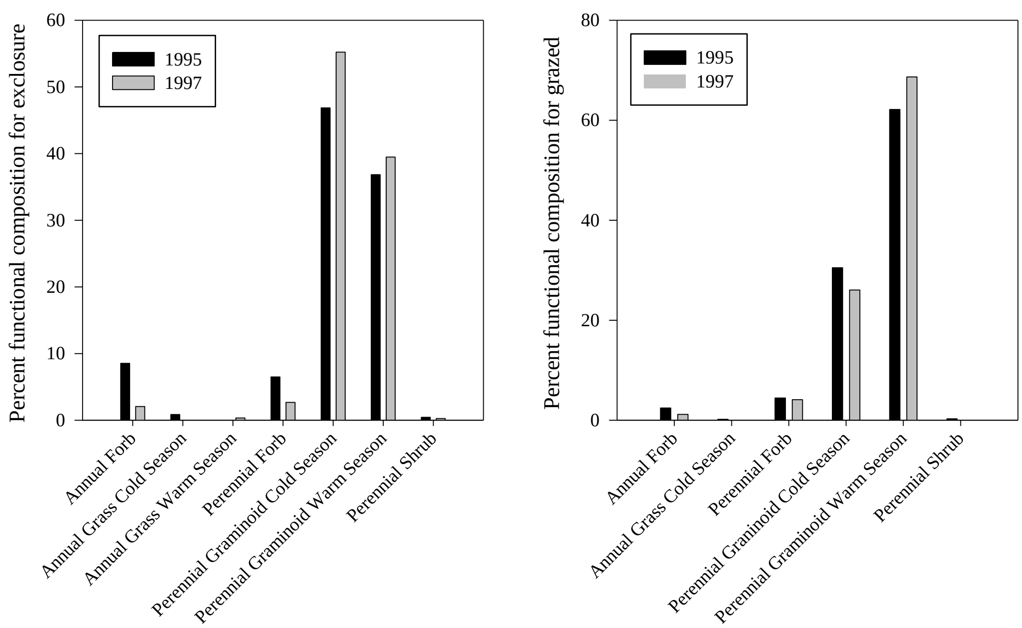


Figure 41. Percentage of functional composition for the grazed transects in 1995 and 1997 and the exclosure (un-grazed) transects in 1995 and 1997, PNG.

Discussion

Grazing effects on shortgrass steppe vegetation were examined with a one-season study and a multi-year study. While several studies have examined grazing stress, few focus on the riparian community despite the preference by cattle for riparian areas when foraging (Schwartz & Ellis, 1981; Senft et al., 1985). Overall community composition and structure, diversity, species-specific responses, and soil characteristics showed few significant differences between moderately-grazed and un-grazed plots.

Hypothesis 1, "vegetation composition and functional group composition of excluded areas will significantly differ from grazed areas," was rejected. No significant change was found in either study. Contrarily, species-specific responses were found in both studies. Only one species was significantly different between treatments in the one-year study with more *Poa segunda* in areas excluded from grazing. Cattle may preferentially choose this grass over other grasses or perhaps this grass does not handle trampling well (Stohlgren et al., 1999). There were other minor differences, such as grazed plots having more *Bouteloua gracilis,* a perennial warm season grass that is well-adapted to low levels of precipitation. Non-grazed plots were characterized by more *Equisetum laevigatum* and *Kochia scoparia*. This could be due to the rigid structure of *Equistetum*, preventing it from handling trampling pressure well because it is not preferentially eaten by cattle (Fujita et al., 2009). The same could be suggested for *Kochia* (Milchunas et al., 1992). These changes in species indicators support the notion that species composition changes in riparian areas when released from grazing.

For the multiple year study, species composition started out different for the exclosures compared to grazed areas demonstrating the heterogeneity of riparian areas of the shortgrass steppe or indicating a rapid change in vegetation composition from one growing season at this site as measurements were not recorded prior to the first season of release from grazing. The lack of significant changed based on the one-year study supports a heterogeneity explanation. Within the five year period, change in vegetation composition occurred both in areas released from grazing and areas exposed to continuous grazing; with more compositional change occurring within the exclosure.

In terms of structure, an increase in litter was observed every year in the exclosure and was consistent with other studies (Hazlett, 1992). This build-up of litter over time could impact which species germinate and will likely change soil composition, but such changes were not evidenced in this study.

Species-specific responses were seen in the multi-year study as well. When comparing the exclosure to grazed transects in 1995, grazed transects were characterized by dominant grasses of the steppe: *Bouteloua gracilis* and *Bouteloua dactyloides* and *Sporobolus airoides*, a grass species adapted to alkali soils. In 1999 grazed transects remained characterized by grasses, but both *Bouteloua gracilis* and *Bouteloua dactyloides* decreased while *Elymus smithii* increased and *Sporobolus ariodes* remained about the same. The exclosures showed a decrease in the grass *Elymus smithii* and the forb *Descurainia pinnata*, an increase in the warm season grass *Elymus lanceolatus*, and a minor increase for forb species in general. *Elymus smithii* decreased in percent cover every year of the study. This decrease was expected in grazed areas where it is a preferred grass but not expected in the un-grazed transects and was contrary to a previous study conducted in upland pastures (Hart, 2001). Perhaps the higher moister content in the riparian area enabled other species to compete with *Elymus smithii*.

The cool season grass taxa *Poa* species remained an indicator species of the exclosures for both years. The abundance of this species in un-grazed areas was consistent for both our studies and may indicate a preference for this species by cattle (Stohlgren et al., 1999; Fujita et al., 2009). The data suggest mild grazing effects with perennial grasses being better adapted to grazing than forbs as supported by previous studies (Amiri et al., 2008). In the absence of grazing, forbs generally become more prominent (Hazlett, 1992; LeCain et al., 2002).

Functional group composition between treatments, like overall species composition, was different throughout the multi-year study. After 1997, the general dynamics of functional types for the exclosure and the grazed areas followed the same pattern. In fact, and contrary to what was hypothesized, the ending points were even more functionally similar than the starting points. Both sites saw a decrease in forbs and an increase in perennial warm-season grasses from 1995 to 1997 that was likely due to the hail storm and early season drought conditions of 1996 (LeCain et al., 2002). By 1999, functional composition in the exclosure was similar to its starting point, but the grazed transects showed movement away from the starting point. Functional group percentages showed an increase in the perennial forbs and perennial cool-season graminoids from 1995 to 1999, potentially due to increased moisture in 1999 that allowed cool season graminoids to out-compete perennial warm season grasses in the grazed environment.

Contrary to expectations, hypothesis 2, “diversity will be greater in exclosures,” was rejected. Grazing had no significant impact on species richness or diversity in either study. Richness and diversity measurements followed the same general patterns for both the exclosure and the grazed transects. The general trend was a decrease initially followed by an increase. The diversity increased sooner in grazed areas (Simpson's index) than the exclosures. Diversity remained less in grazed transects throughout the study which is expected as grazing is predicted to decrease diversity in dry environments (Olff & Ritchiee, 1998). Richness of species decreased for the first four years but increased substantially in the last year of the study. Richness increased more in the released transects than grazed transects. Both areas experienced a decrease in indicator species over time, but in the exclosures this decrease in dominant species was less pronounced with a decrease in evenness observed. This decrease in evenness in exclosures is consistent with a previous study (Hart, 2001). The changes noted in richness and evenness support the hypothesis that composition will differ for areas released from grazing given adequate time.

Hypothesis 3, "biomass and maximum height of plants will be greater in the excluded plots following one grazing season," was accepted for height and above ground biomass but rejected for belowground biomass. In one growing season, grazing had a profound impact on above-ground biomass. This was expected since forage was consumed by cattle. Below-ground biomass was not impacted by grazing, indicating that many plants on the shortgrass steppe have adapted to grazing pressure (Milchunas et al., 1988a). The consistent growth of roots even when exposed to grazing can be seen in the lower shoot to root ratios for grazed areas. Other studies support the claim that grazing has minimal impact on belowground biomass (Milchunas & Lauenroth, 1989) and in some cases even increases below ground biomass (Van Der Maarel & Titlyanova, 1989). The selective grazing pressure has been prevalent for many years on the shortgrass steppe, including bison grazing throughout the last few centuries (Larson, 1940; Lauenroth & Milchunas, 1991a). Apparently, riparian areas are similarly adapted to grazing pressure.

Maximum plant height was greater in plots that were not exposed to grazing. The tallest species differed with each treatment indicating certain plants may be better adapted than others to withstand the impacts of grazing or crowding (Cingolani et al., 2005). Dominant tall plants in grazed areas included *Carex stenophylla*, *Descurainia pinnata*, and *Ratibida columnifera*. In the absence of grazing, *Equisetum laevigatum*, *Hesperostipa comata* and *Nessella viridula* were able to outgrow other species. These plants may be better competitors in crowded environments as they are able to grow above other species to utilize more solar radiation (Grime, 1977). *Elymus smithii* and *Sporobolus airiodes* occurred as the tallest species in both grazed and un-grazed plots indicating they are generalist species (Pywell et al., 2003) growing well in both grazed and crowded environments.

Hypothesis 4, “heterogeneity will be greater in grazed areas,” was rejected. Although, over one grazing season, patchiness increased in plots that were grazed. While not yet significant, more bare ground present in the grazed plots could contribute to a decrease in ground cover over time. But, data from the longer-term study did not show a significant increase in percentage of bare ground for grazed transects. This data is in contrast to previous studies showing an increase in bare ground in response to grazing (Schultz & Leininger, 1990; Hazlett, 1992 ; Derner & Hart, 2007).

Hypothesis 5, “soil nutrient composition will be significantly different for un-grazed compared to grazed plots,” was rejected. Soil nutrient composition was not different for grazed plots compared to un-grazed plots over one growing season. The increase in cattle dung in areas exposed to grazing should increase phosphorus, nitrogen and potassium over time. Since cattle spend more time in riparian areas than upland areas (Schwartz & Ellis, 1981; Senft et al., 1985), an increase in nutrient levels could contribute to structural changes in riparian areas compared to upland areas. Previous studies indicate that lowland areas do have increased amounts of carbon, phosphorus and nitrogen, but attributed these differences to increased plant biomass and sediment movement, not cattle grazing (Schimel et al., 1985; Burke et al., 1999). Phosphorus levels from our analysis were similarly within the higher range determined for lowland areas (Schimel et al., 1985).

Limitations to the studies conducted included lack of replication for the transect study and lack of initial homogeneity for the grazed and un-grazed transects. In addition, some ambiguity on species identification occurred due to some of the technicians being different from year to year. Future studies should include multiple study sites and include exclosures and grazed areas alternating at each site. In addition utilizing the same crew every year would eliminate some of the ambiguity.

Because of the similar patterns seen with both treatments for evenness, richness, species diversity, change in species composition, and change in functional composition, and lack of significant changes observed between treatments, some variable other than grazing is likely driving vegetation dynamics. To investigate if climate may be driving change observed over this period of time, annual climate data from the weather station located on the CPER site (Latitude: 40.800278 S, Longitude: -104.730556 E) were investigated. One major climate event that appears to have had dramatic impact on the study site was a major hail storm of 29 July 1996. Weather station data indicated golf ball-sized hail during this storm (weather station data) and Mary Ashby (CPER Site Manager of the Ag Research Service) indicated data collection for 1996 was terminated because of damage caused by this storm; it prevented the accurate identification of plant species.

The general trends seen as a decrease in richness, evenness and diversity observed in 1997 support the suggestion that a hail event had a significant impact on vegetation composition. Hail falls frequently on the shortgrass steppe (Pielke & Doesken, 2008), causing this region of the country to be affectionately termed “hail alley” (Dennis, 1992). In particular, hail has contributed to the abundance of *Opuntia polyacantha* which utilizes the impact of hail to propagate via fragmentation. This disturbance event may explain the general decline in richness from 1995 to 1998 in both the exclosure and grazed transects followed by an increase in richness in 1999. One could postulate that recovery from the event was occurring but had not yet increased to pre-event levels by year four. The decrease in Simpson’s diversity correspondingly occurred for three years in the exclosures but only for two years in the grazed areas. Perhaps grazing helps moderate the impacts of the hail event, or grazed areas were more resilient. Because exclosures had greater diversity, they recovered faster (greater resilience) from this disturbance compared to grazed transects (Tilman et al., 1997).

For the exclosure, indicator species shifted but included a mixture of both forbs and grasses from 1995 to 1999. For the grazed transects, the indicators shifted from a forb and grass combination to exclusively grasses being indicators, perhaps due to an increase in grazing intensity. In addition, fewer indicator species were identified for either treatment in 1997. Hail damage likely has a more profound impact on exclosures than grazed areas. In a previous study, leaf area increased in exclosures for both grasses and forbs (Hazlett, 1992) exposing more surface area to hail damage. Another study showed susceptible of vegetation within exclosures to hail damage (LeCain et al., 2002). In general, perennial species increased compared to annuals for both the grazed and ungrazed sites in 1997, perhaps because the damage to annual plants prevented them from producing seeds in 1996. The elevated stress of hail and grazing shifted the grazed community toward the hardy grass species *Disticalis stricta*. Based on species percentages, *Sporobolus ariodes* and *Disticalis stricta* appear to be resilient to the disturbances that impacted many other species.

In addition to the hail event, other climate patterns were related to the changes observed in species richness and diversity (Figure 42). In general, an increased average precipitation corresponded to an increase in species richness and diversity. There also appeared to be an inverse relationship between average wet and dry bulb temperature and species richness and diversity. Generally, as average wet and dry bulb temperatures increased, species richness and diversity decreased. Taken together, warmer, drier conditions affect community diversity on the shortgrass steppe and annual species composition respond to variation of this limiting factor (Epstein et al., 1999).

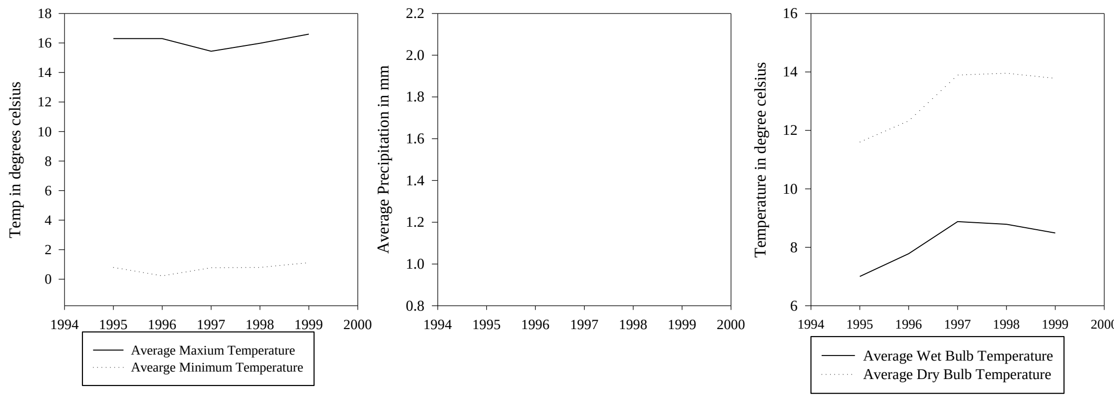


Figure 42. Weather data from the CPER site (40.800278S,-104.730556E). Data base: Standard Met Data: 1969- 2010 Manually Collected Standard Meteorological Data (http://sgs.cnr.colostate.edu/dataset_view.aspx?id=man11_climdb accessed 2-4-12)

From the above studies, it can be concluded that riparian areas on the shortgrass steppe are heterogeneous in terms of species composition and that climate is a more direct driver of shortgrass steppe vegetation composition than grazing. Prior research corroborates the idea that grasslands adapted to water-limiting environments are also resilient to grazing (Rutherford et al., 2012). Release from grazing may change riparian vegetation composition on the shortgrass steppe over a long time period, but dramatic change was not seen in these short-term studies. The data indicate that release from moderate grazing has minimal impact on riparian areas of the shortgrass steppe and that changes in functional species composition and community structure are similar to changes occurring in upland areas of the shortgrass steppe. However, because of species unique to riparian areas of the shortgrass steppe (Appendix B and C) and increased species diversity (Stohlgren et al., 1998), continued monitoring is recommended to determine if grazing is changing riparian communities.

CHAPTER IV

ASSESSMENT OF COMPETITION BETWEEN NOXIOUS WEEDS AND FUNCTIONALLY EQUIVALENT NATIVES UTILIZING FIELD AND GREENHOUSE STUDIES

Abstract

Community composition is determined to a large extent by the interactions among plants. Large scale disturbances such as mining decrease the diversity of plant communities and cause a shift from native plants to ruderal invasive plants. A goal of restoration is to develop an ecosystem functioning similar to that prior to the disturbance. Such mitigation can be accomplished through soil augmentation, re-vegetation and weed control. This study investigates the possibility of utilizing native functionally equivalent plants as a means to control the spread and dominance of noxious weeds. Greenhouse and field studies were conducted to investigate the impact plant functionality and nativeness has on competitive ability of the ubiquitous noxious species *Bromus tectorum* and *Cirsium arvense*. Results indicate that *Vulpia octoflora* may inhibit the growth of *Bromus tectorum* but has little impact on *Cirsium arvense* and that *Achillea millifolium* var. *lanulosa* does not significantly impact the growth of these noxious weeds. In the field, increased graminoid cover predicted decreased performance of *Cirsium arvense*. Our results indicated that the current practice of planting native perennial grasses in

reclamation sites is an effective control measure for containing *Cirsium arvense* on the shortgrass steppe and that planting *Vulpia octoflora* may be useful in controlling *Bromus tectorum*.

Introduction

A goal of ecological restoration is to facilitate the recovery of degraded landscapes to a previous level of biodiversity and ecological function (SER, 2004). In many severely disturbed areas, plant diversity decreases (Collins & Barber, 1985; Hobbs & Huenneke, 1992) and species that do thrive are often introduced noxious plants (Hobbs & Harold, 1991; Larson, 2003). This increase in noxious invasive plants is due to their ability to disperse to disturbed areas and utilize resources (Marvier et al., 2004).

The threat of noxious invasive weeds in natural landscapes is a major concern due to the functional degradation they cause to a community (Vitousek et al., 1996). In disturbed areas such as roadsides, mined sites, and construction sites, invasive species often dominate. Invasive plants have characteristics that enable them to rapidly colonize areas vacated by native plants following a disturbance. Reasons for their success include the ability to grow well in harsh abiotic conditions such as poor soils and low moisture levels (Daehler, 2003) and to propagate rapidly (Grime, 1977). These characteristics coupled with limited natural predators (Wolfe, 2002) and allopathic characteristics (Thorpe et al., 2009) ensure – once established – invasive weeds perpetuate in degraded environments. This persistence hinders native plant re-establishment (Eliason & Allen, 1997) and creates challenges for humans with decreased cattle and crop production, decreased ecosystem function and degradation of recreational areas (DiTommaso, 2000; Pimentel et al., 2000).

In the case of some disturbances such as aggregate mining, not only have the existing native plants been removed, but the seed bank has also been removed preventing the rapid reestablishment of plants that do not have long-distance dispersal methods (Kirmer et al., 2008). Thus, restoration of communities may require direct impute of seeds (Seabloom et al., 2003).

A number of management techniques have been developed to control the introduction and spread of noxious invasive weeds including herbicide treatment, manual removal, mowing and prescribed burning (DiTommaso & Johnson, 2006). Of these techniques, herbicide use predominates (Haggar et al., 1986; DiTommaso, 2000). Herbicide use has been shown to have negative impacts on the environment and particularly people in the environment as herbicide can contribute to cancer (Hoar et al., 1986; Orsi et al., 2009). Herbicide use also has collateral effect on native plant species (Carlson & Gorchov, 2004), residual effects in the soil (Felixa et al., 2007), and impacts aquatic ecosystems (Fairchild et al., 1997). A need exists for utilizing ecological principles in restoring invasive-infested landscapes (Sheley & Krueger-Mangold, 2003), such as biotic controls (McEvoy & Coombs, 1999) and the use of functionally equivalent native plants as alternate means of controlling noxious weeds.

Plants are often classified based on their family groupings, but can also be classified based on their functional groupings (Gitay & Noble, 1997). Plant functional diversity appears to be equally import to ecosystem processes as species diversity and predicts dynamics within a community (Diaz & Cabido, 2001). Two broad categories are generally employed in determining functional classification; species utilizing the same resources or species responding similarly to disturbances (Gitay & Noble, 1997). To determine these characteristics, plants are often classified based on their growth form (graminoid, forb, sub shrub, shrub, tree), growth characteristic (annual, biennial, or perennial), metabolic pathway (C_3, C_4, CAM), or their interaction with soil nutrient pools (nitrogen fixers and selenium indicator species) (Paruelo & Lauenroth, 1996; Lavorel et al., 1997).

Plants in the same functional grouping utilizing similar resources will compete with each other. Competition is the process through which plants vie for limited resources such as light, water, or nutrients (Darwin, 1859). Successful competitors will be plants that are able to grow larger faster, or more efficiently use resources, and ultimately produce the most viable seeds. Competitive ability can therefore be measured by growth parameters and fecundity. Correctly identified functionally equivalent plants should prevent each other from coexisting in the same location (micro-scale) in an ecosystem (Gause, 1934; Hardin, 1960). For this reason, many competition hypotheses predicted that intraspecifc competition would be greater than interspecific competition (Tilman, 1988). Current research, however, is inconclusive (Bengtsson et al., 1994; Thacher et al., 2009a). In some situations, species seem to facilitate the growth of other plants (Callaway & Walker, 1997). In addition, because of limited resources, plants are negatively impacted by increased plant density (White & Harper, 1970), but this negative impact becomes less apparent in species demonstrating high levels of physiological plasticity (Harper & Gajic, 1961).

At the local level, competition excludes similar plant species, but at the landscape level, functionally similar plant species are expected to coexist because they thrive in similar biotic and abiotic environments (Aarssen, 1989; Bengtsson et al., 1994). Darwin recognized this paradox and predicted similar exotic species should invade communities because of phylogenetic relatedness, but his naturalization hypothesis contrarily predicted that similar taxa are prevented from invading because they encounter similar functional species that results in a strong competitive relationship (Wolfe, 2002; Thuiller et al., 2010). Therefore, exotics that are functionally different are more likely to successfully invade communities (Diez et al., 2008) because they can utilize resources differently and fill a void not occupied by current vegetation (Elton 1958, MacArthur 1970, Tilman 1997). For example, a species that has deeper roots than the native vegetation would have an advantage in sequestering water and would have the ability to grow without strong competition for resources. It logically follows that increased species and functional richness prevents species invasion because more of the available space and resources are being used by the current species. Communities with low levels of diversity will afford opportunities for invaders (Elton 1958, MacArthur 1970, Tillman 1997, Kreyling et al. 2008). The concept holds for small-scale plots in some cases (Maron & Marbler, 2007) but not in others (Davies et al., 2007) and also does not appear to hold at the regional scale (Stohlgren et al., 1999).

Previous studies have investigated the influence of plant functionality on invasive species (Vila & Weiner, 2004). At the community level, results indicate that increased functional diversity either hindered invasion (Symstad, 2000; Carpinalli et al., 2004; Hooper & Dukes, 2010) or had no effect on invasive plant growth (Carpinelli et al., 2004). At the species level, perennial grasses increased resistance to invasion by the annual noxious grass Medusahead (*Taeniatherum caput-medusae*) (Sheley & James, 2010). Likewise, the density of the perennial rhizomatous forb Russian knapweed

(*Acroptilon repens*) decreased at one research site when planted with a forb but not at all sites (Mangold et al., 2007). Functionally equivalent annual forbs decreased the impact of the noxious annual forb *Centaurea solstitalis* (Dukes, 2000), and competition from native perennial grasses resulted in decreased biomass of the invasive forb *Cirsium arvense* (Ang et al., 1995) These studies lend support to the idea that functionally equivalent natives effectively control noxious weeds. However, a specific need exists for investigating this question on more species and in more regions, particularly in the short grass steppe where no such studies exist.

Species adapted to the shortgrass steppe must have the ability to deal with periodic water limitations. This filter of invasion has resulted in relatively low levels of exotic species on the shortgrass steppe (Mack & Thompson, 1982). However, in lowland and riparian areas where water becomes less limiting and sites are generally more productive, exotic species become more abundant (Kotanen et al., 1998). Many restoration efforts on the shortgrass steppe involve planting native grasses but not forbs. However, some of these excluded native forbs may successfully compete with invasive plants, especially in riparian areas.

This study focuses on utilizing native functionally equivalent plants to control the abundance and spread of noxious weeds. Of particular interest is the efficacy of utilizing native forbs to control exotics in reclamation efforts in more mesic areas of arid grasslands. Our overarching hypothesis is than native species will inhibit the growth of functionally equivalent noxious weeds. If correct, native plant restoration techniques could decrease the dependency on herbicide in managing noxious invasive weeds. Specifically, we set up two greenhouse experiments to investigate the competitive interaction between *Bromus tectorum*, *Cirsium arvense, Achillea millifolium* var. *lanulosa* (native), and *Vuplia octoflora* (native). In addition, we conducted a field experiment investigating in situ competition of *Cirsium arvense*. Specifically, we hypothesized that: (1) competition will increase with increased plant density; (2) non-native species will grow better with native species than with non-native species, (3) functionally equivalent natives will competitively inhibit functionally equivalent noxious weeds more than functionally different natives, and (4) significant intraspecific competition will occur for the species.

Methods

Site Locations and Characteristics

The greenhouse studies were conducted in the University of Northern Colorado greenhouse (N 40˚ 24’ 7.59”, W 104˚ 41’ 56.07”) and the field study was conducted at the PLC and adjacent land along the Cache la Poudre River corridor of Weld County, CO (N 40˚ 26’ 56.79”, W 104˚ 48’ 52.80”). All field plots were located within 1.4 km of each other and ranged in elevation from 1436 m to 1442 m (Figure 43). Plots were located both north and south of the Cache la Poudre River. Soils consisted predominantly of Aquolls and Aquents with some Kim loam and Otero sandy loam (USDA Soil Conservation Service 2012). The entire research area has been impacted by human disturbance including gravel mining, road building and long-term agriculture. Plot locations were selected based on the presence of *Cirsium* plants.

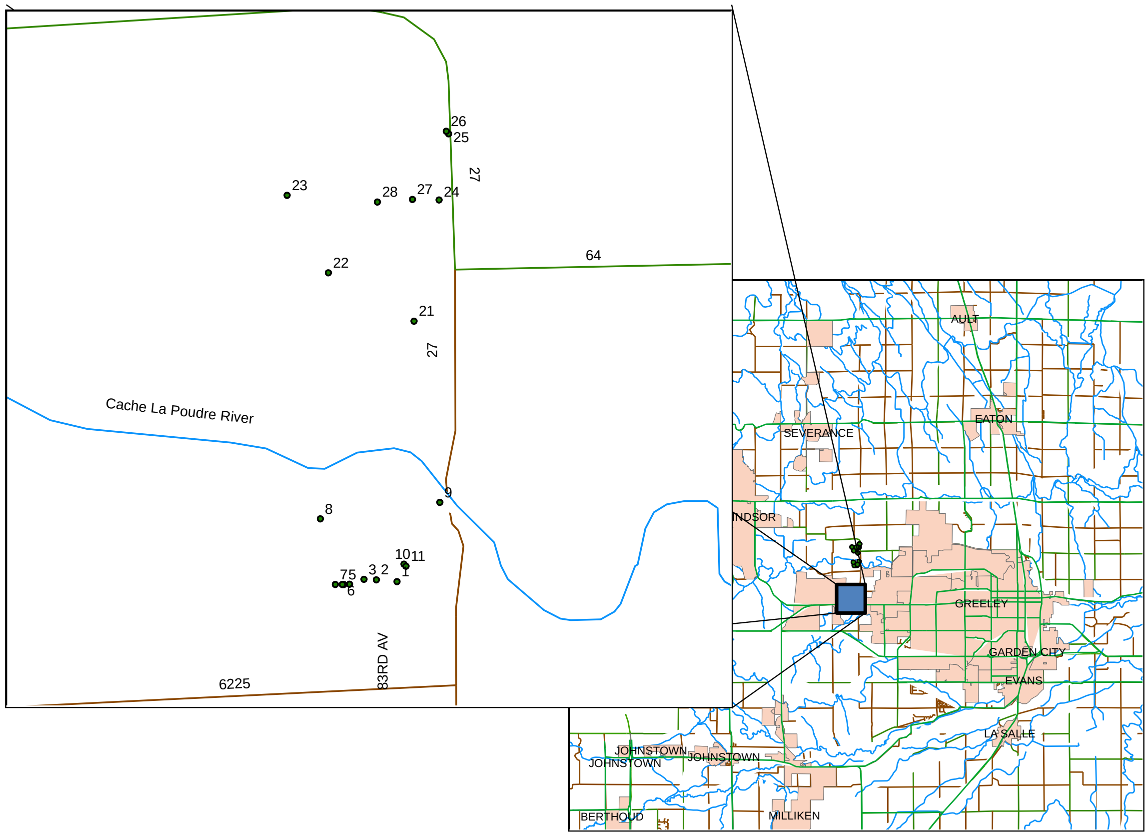


Figure 43. Research locations of paired plots investigating *Cirsium arvense* competition occurring naturally, Weld County, Colorado.

Research Species

Cirsium arvense

Canada thistle, *Cirsium arvense*, a noxious perennial forb from the Asteraceae family, grows by underground rhizomes with a root structure that commonly grow at 2 - 3 m depths in the soil. It is ubiquitous across Colorado and is common in moist habitats (Moore, 1975). In addition to asexual reproduction, it also reproduces from seed. Plants produce both male and female flowers with up to 100 seed heads per plant producing up to 1,500 seeds per plant which stay viable in the soil for up to 20 years (Moore, 1975; Beck, 2008). Once it becomes established, roots play an important role in maintaining the species. As little as 1.25 cm of root stock is needed to develop vegetative structure (Hayden, 1934).

Achillea millefolium* var. *lanulosa

The perennial aromatic forb *Achillea millefolium* var. *lanulosa* (western yarrow) is a polyploid (Ehrendorfer, 1973) that has a wide distribution in the United States (Pollard 1899) including riparian zones in Colorado (Baker, 1989). The species is rhizomatous and adapted to a wide variety of soil types, including dry sandy soils, and is able to tolerate periodic drought. It can reproduce both sexually and asexually (Warwick & Black, 1982). Similar to *Cirsium*, *Achillea* is in the family Asteraceae and a functional equivalent of *Cirsium*.

Bromus tectorum

Cheat grass *B. tectorm*), classified as a noxious weed, is a short-rooted annual C_3 grass in the family Poaceae. It germinates either in the fall or early spring (Skinner, 2008) and greens up quickly before other plants are able to compete for resources. It is the most abundant invasive species in the shortgrass steppe and has been in Colorado since before 1900 (Mack, 1981). It has prolific seed production and dispersal ability with seeds remaining viable for up to 11.5 years (Hulbert, 1955). Seeds are produced by individuals less than 45 days old (Mack & Pyke, 1983). It has fibrous roots that extend into the soil up to 1.4 m (Hulbert, 1955) and has the ability to exude phenolic compounds that create an environment inhospitable to competing plants: although, *Bromus tectorum* exudes less of these allopathic compounds than other *Bromus* species (Holzsapfel et al., 2010).

Vulpia octoflora

Vulpia octoflora (six week fescue) is a widely distributed short-lived annual native C_3 grass adapted to dry climate (Shaw, 2008) and is widely distributed across western rangelands. The species is not preferred by cattle and produces more seed in response to increased precipitation. It is classified as a winter grass and is one of the first plants to grow in the spring (Houston & Hyden, 1976), typically completing its life cycle prior to other plants. *Vulpia* is like *Bromus* in the Poaceae family and they are functional equivalents.

Greenhouse Study: Density – Functionality – Intraspecific for Noxious

Seeds of *Bromus tectorum* (collected in the field around Greeley, CO), *Cirsium arvense* (collected in the field around Greeley, CO), *Vulpia octoflora*, (purchased from Pawnee Buttes Seeds Inc., Greeley, CO), and *Achillea millefolium* var. *lanulosa* (purchased from Pawnee Buttes Seeds Inc., Greeley CO) were planted in trays in the University of Northern Colorado greenhouse. After germination, plants were grown for two weeks and subsequently transplanted into 25.4 cm diameter pots containing 70% sand (Quickrete Playsand) and 30% potting soil (Miracle Grow potting mix) and fertilized (fertilome geranium and hanging basket soluble plant food; N 20% (5.0% Ammoniacal Nitrogen, 5.9% Nitrate Nitrogen, 9.1% Urea Nitrogen), P_2O_5 20%, K_2O 20%; 5 ml per 3.8 L of H_2O). The noxious plants were grown with functionally equivalent native plants, with functionally different native plants, and with themselves at three density levels (1x1, 2x2, 3x3). For example, *Cirsium arvense* was grown with *Achillea millefolium* var. *lanulosa*, with *Vulpia octoflora* and with itself. Likewise

Bromus tectorum was grown with *Vulpia octoflora,* with *Achillea millefolium* var. *lanulosa* and with itself (Table 20). Native plants were not grown with each other. Ten pots for each treatment were used and these pots were randomly placed on greenhouse benches (N=180, n=10). For each plant, initial measurements of height and number of leaves were recorded. Each pot was watered for one minute daily using an automated sprinkling system. Following eight weeks growth, final heights and number of leaves were recorded for each plant. Growth gain was determined by subtracting the initial measurements from the final. In addition, for *Vulpia octoflora* number of spikelets per plant was recorded. Plants were harvested to obtain oven dry weight (ODW) of above ground and below ground biomass after being dried for 48 hours at 75˚C. Following drying, each sample was massed to determine above and belowground biomass. All measurements were standardized to one plant by averaging variable measurements in pots with multiple plants.

A two-way ANOVA with density level and functional similarity was conducted both for the noxious weeds and for the native species. For the noxious weeds, functional types included equivalent, different, and same species (intraspecific); for the native plants, functional types included equivalent and different species (Table 20). Intraspecific competition was not investigated for the native plants in this experiment. If treatments were not normally distributed, data were log transformed prior to conducting the analysis.

Greenhouse Study: Nativness – Functionality – Intraspecific

A follow up study utilizing the same plant species was set up to assess the impact of functionality but also to investigate the impact of nativeness. Intraspecific competition was investigated for all species.

Table 20. Density levels utilized in the experiment and functional relationships between the noxious species *Bromus tectorum*, *Cirsium arvense* and native species *Achillea millefolium* and *Vulpia octoflora*.

Species	**Native/Noxious**	**Functionally Equivalent**	**Functionally Different**	**Same Species (Intraspecific)**	**Density**
Bromus tectorum	Noxious	*Vulpia octoflora*	*Achillea millefolium* var. *lanulosa*	*Bromus tectorum*	1 x 1 2 x 2 3 x 3
Achillea millefolium var. *lanulosa*	Native	*Cirsium arvense*	*Bromus tectorum*	—	1 x 1 2 x 2 3 x 3
Vulpia octoflora	Native	*Bromus tectorum*	*Cirsium arvense*	—	1 x 1 2 x 2 3 x 3
Cirsium arvense	Noxious	*Achillea millefolium* var. *lanulosa*	*Vulpia octoflora*	*Cirsium arvense*	1 x 1 2 x 2 3 x 3

Set up was similar to the previous study except density levels were consistent at 2 X 2 for each pot and plants were grown for 11 weeks. Noxious plants were gown with noxious plants, natives were grown with natives, and noxious were grown with natives (*Bromus-Bromus*, *Bromus-Achillea*, *Bromus-Vulpia*, *Bromus-Cirsium*, *Cirsium-Cirsium*, *Cirsium-Vulpia*, *Cirsium-Achillea*,*Vulpia-Vulpia*, *Vulpia-Achillea*, *Achillea-Achillea*; N=100; n=10; Table 21). In addition, individual plants of each species were transferred to pots and served as a control indicating growth without competition (N=40; n=10).

A two-way ANOVA with nativeness and functional similarity was conducted both for the noxious species and for the native species. For each species, functional type levels were equivalent and different and nativeness levels were noxious and native (Table 21). If treatments were not normally distributed, data were log transformed prior to conducting the analysis. Intraspecific competition was investigated by an ANOVA that included the growth variables from the control plot. Contrasts were run against the control to determine if significant differences existed between the treatment means of species grown with itself or with other species (Table 22). If treatment measurements were not normally distributed, data were log transformed prior to conducting the analysis.

Table 21. Two-way ANOVA setup comparing the relationship functionality and nativeness have on competition of the noxious species *Bromus tectorum* and *Cirsium arvense* and native species *Achillea millefolium* and *Vulpia octoflora*.

Species	**Native/Exotic Noxious**	**Functionally Equivalent Exotic**	**Functionally Equivalent Native**	**Functionally Different Exotic**	**Functionally Different Native**
Bromus tectorum	Exotic Noxious	*Bromus tectorum*	*Vulpia octoflora*	*Cirsium arvense*	*Achillea millefolium* var. *lanulosa*
Achillea millefolium var. *lanulosa*	Native	*Cirsium arvense*	*Achillea millefolium* var. *lanulosa*	*Bromus tectorum*	*Vulpia octoflora*
Vulpia octoflora	Native	*Bromus tectorum*	*Vulpia octoflora*	*Cirsium arvense*	*Achillea millefolium* var. *lanulosa*
Cirsium arvense	Exotic Noxious	*Cirsium arvense*	*Achillea millefolium* var. *lanulosa*	*Bromus tectorum*	*Vulpia octoflora*

Table 22. Contrasts set up to investigate intraspecific and interspecific competition of the experimental species.

Control	**Intraspecific**	**Interspecific**
Bromus	*Bromus X Bromus*	*Bromus X Achillea, Bromus X Cirsium, Bromus X Vulpia*
Vulpia	*Vulpia X Vulpia*	*Vulpia X Achillea, Vulpia X Bromus,Vulpia X Cirsium*
Achillea	*Achillea X Achillea*	*Achillea X Bromus, Achillea X Cirsium, Achillea X Vulpia*
Cirsium	*Cirsium X Cirsium*	*Cirsium X Achillea, Cirsium X Broums, Cirsium X Vulpia*

Field Study: Determination of Cirsium arvense competition in situ

Greenhouse studies have advantages (Gibson et al., 1999) but do not adequately account for all of the biotic and abiotic variables impacting plants in their natural environments (Tilman, 1988; Goldberg & Barton, 1992; Grime, 2001). To determine competition of *Cirsium arvense* in its natural environment, a field study was conducted.

Nineteen paired plots (n=38) each containing a centrally located *Cirsium arvense* were selected (Figure 44). Each plot pair was separated by ≤ 3 m. Initial ground cover vegetation was recorded for each plot on May 19, 2011. Sites were selected that had similar initial starting *Cirsium* characteristics (height, number of leaves, and longest leaf) and similar ground cover. An NMS Ordination using the cover values was conducted to visually determine if starting pairs had similar vegetation. Specific parameters for this test included a Sorensen (Bray-Curtis) distance measure with 50 runs and two axes; the stability criterion was set at 0.00001 with 15 iterations. The maximum number of iterations was set at 100 with step down in dimensionality. The initial step length was 0.20 with random numbers serving as the source (100 randomizations). To statistically verify the results of the NMS, MRPP analysis was conducted.

Following the initial recording of ground cover, one of the paired plots was randomly selected and served as a control. Within the control plots, all of the vegetation but the centrally located *Cirsium* was removed. Continued removal of vegetation in these plots was conducted weekly throughout the length of the experiment. In the competition plots, vegetation was not removed. Weekly measurements of growth parameters (height, longest leaf, number of leaves, and number of flowers) for *Cirsium* were recorded for both control and competition plots through peak biomass (July 14, 2011). Final ground cover measurements were made at this time for the experimental plots. In addition, above-ground vegetation was harvested and dried at 75 °C in a drying oven for 48 hours prior to being massed (ODW).

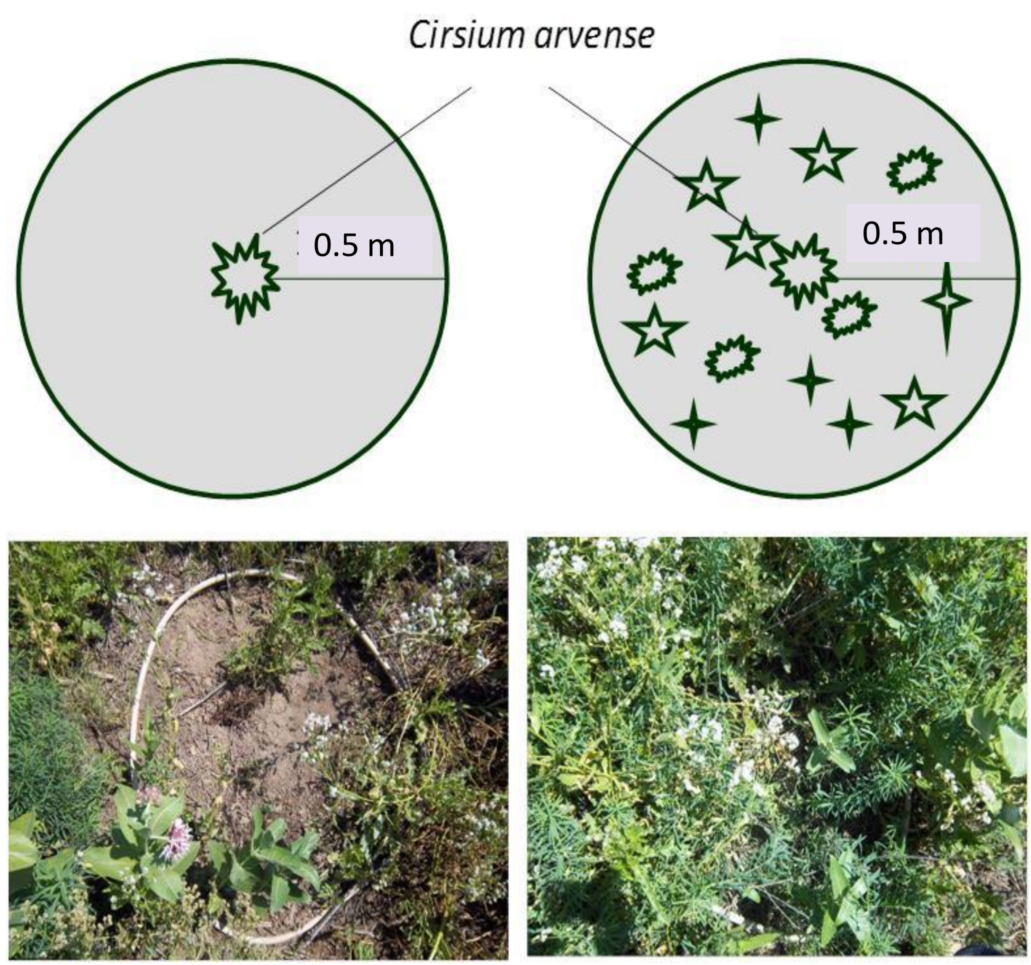


Figure 44. Paired plot design and photographs of the paired plot in the field, Weld County, CO.

Of the initial 19 paired plots, only nine were utilized in the data analysis (1, 8, 9, 22, 23, 24, 25, 26, and 27). Ten were excluded from analysis because nine of the paired plots were lost to flooding (2, 3, 4, 5, 6, 7, 10, 11, and 21; Figure 45) and one (28) was lost to herbicide. The flooding allowed for an investigation of competition effects on *Cirsium* recovery as some of the plants recovered. To investigate this question, Fisher's exact test was run comparing survivorship in treatment to control plots.

To compare growth rates for the non-flooded plots, average growth parameters were plotted over time. The impact of competition was investigated by taking the final growth variable measurements from the experimental and control plots and comparing them utilizing a paired t-test.

Figure 45. Evidence of flooding in the research area.

Final percent ground cover for each of the experimental plots was categorized into percent forb and percent graminoid as well as percent native and percent invasive. A forward stepwise regression was employed (SAS program) to determine if the percentage of forbs or the percentage of invasive species in the plot could predict success of *Cirsium arvense*. Percent cover served as the independent variable and growth parameters served as the dependent variable. Prior to running the analysis, a Parson correlation was conducted to determine multicollinearity. Variables were not included in the analysis if they demonstrated correlation > 0.9.

Results

Greenhouse Study: Density – Functionality – Intraspecific for Noxious

Global ANOVA results indicated that number of leaves was significantly different for *Achillea*, *Cirsium* and *Vulpia* for one of the effects (Table 23). The two-way ANOVA determined the main effect of density level to be the cause of statistical difference. Specifically for all species, plants grown with only one other plant grew more leaves than when grown with multiple plants. There was no significant difference between the higher density levels: plants grew equally well at the 2 x 2 and the 3 x 3 levels (Figure 46, 47, and 48). *Bromus* displayed similar trends in relationship to density, but none significantly. No other variables were significant for any of the species. Although for *Vulpia*, all of the growth variables were less when grown with *Bromus* than when grown with *Cirsium,* suggesting a competitive effect of *Bromus* on *Vulpia*. No mortality was seen at these density levels and no other trends were identified from this study.

Greenhouse Study: Nativeness – Functionality – Intraspecific

The same species were utilized to investigate the effect functionality and nativeness had on competition. Global ANOVA identified significant interactions between functional group and nativeness for below ground biomass and number of leaves of *Achillea* (Table 25, 26). Below ground measurements were higher when grown with the functionally similar noxious species *Cirsium* but not with the functionally different noxious species *Bromus*. The same interaction effect was noted for number of leaves. Similar to the biomass measurements *Achillea* grew more leaves with *Cirsium* than it did with *Bromus*. No significant effect of functional similarity or nativeness was observed for height (Figure 49).

Table 23. Global ANOVA results for *Achillea millifolium* var. *lanulosa*, *Bromus tectorum*, *Cirsium arvense*, and *Vulpia octoflora* investigating the impact density and functionality have on growth. Plants grown in UNC greenhouse, Greeley, CO.

Species	Variable	F-Value	P – value
Achillea	Above ground biomass	0.63	0.6795
	Below ground biomass	1.10	0.3720
	Height	2.21	0.068
	Number of leaves	8.23	<0.0001*
Bromus	Above ground biomass	1.69	0.114
	Below ground biomass	1.27	0.268
	Height	1.24	0.288
	Number of leaves	1.14	0.344
Cirsium	Above ground biomass	1.45	0.191
	Below ground biomass	1.75	0.102
	Height	0.41	0.910
	Number of leaves	2.20	0.036*
Vulpia	Above ground biomass	2.02	0.092
	Below ground biomass	1.10	0.373
	Height	1.50	0.204
	Number of leaves	6.78	0.0003*

Table 24. Two-way ANOVA analysis investigating the significance of plant density, competition and density competition interaction for number of leaves for *Achillea millifolium* var. *lanulosa*, *Cirsium arvense* and *Vulpia octoflora*.

Species	Variable	Density P-value	Functional type P-value	Interaction P-value
Achillea	Number of leaves	<0.0001*	0.0849	0.0840
Cirsium	Number of Leaves	0.0019*	0.6015	0.5947
Vulpia	Number of leaves	<0.0001*	0.0807	0.7063

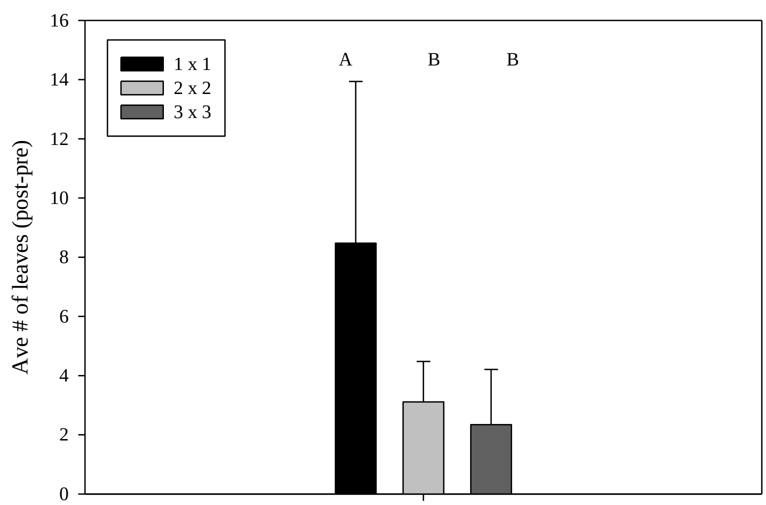


Figure 46. Growth variable average number of leaves for *Achillea millifolium* var. *lanulosa*. in response to density levels. Letters indicate significant differences (Student-Newman-Keuls *post hoc* test).

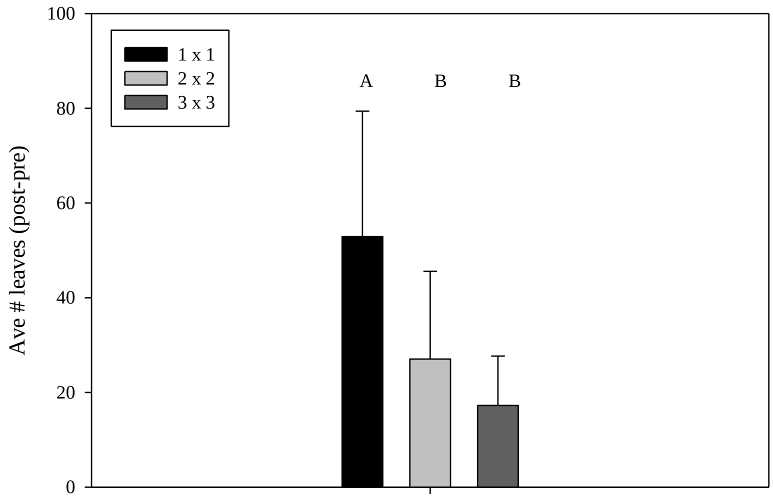


Figure 47. Growth variable average number of leaves for *Vulpia octoflora* in response to density levels. Letters indicate significant differences (Student-Newman-Keuls Test *post hoc* test).

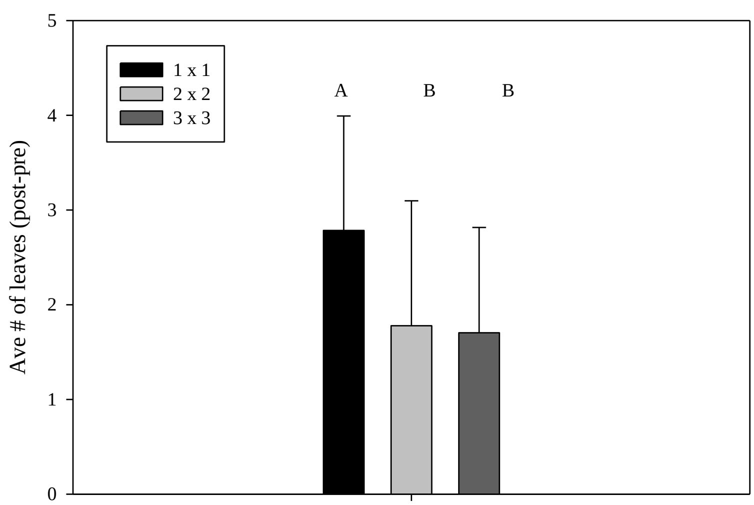


Figure 48. Growth variable average number of leaves for *Cirsium arvense*. Letters indicate significant differences (Student-Newman-Keuls Test *post hoc* test).

Table 25. Global ANOVA results for *Achillea millifolium* var. *lanulosa, Bromus tectorum*, *Cirsium arvense,* and *Vulpia octoflora* investigating the impact nativeness and competition has on growth. Plants grown in UNC greenhouse, Greeley, CO.

Species	Variable	F-Value	P – value
Achillea	Above ground biomass	5.22	0.004*
	Below ground biomass	4.88	0.006*
	Height	0.91	0.446
	Number of leaves	15.1	<0.0001*
Bromus	Above ground biomass	4.91	0.006*
	Below ground biomass	2.45	0.08
	Height	1.62	0.203
	Number of leaves	3.28	0.032*
Cirsium	Above ground biomass	0.29	0.836
	Below ground biomass	0.01	0.999
	Height	1.27	0.298
	Number of leaves	1.89	0.148
Vulpia	Above ground biomass	1.37	0.268
	Below ground biomass	0.49	0.691
	Height	1.43	0.25
	Number of leaves	3.42	0.028*
	Floret #	0.55	0.653
	Floret mass	0.86	0.475

Table 26. Two-way ANOVA analysis investigating the significance of plant nativeness, functionality and nativeness functionality interaction for number of leaves for and biomass for *Achillea millifolium* var. *lanulosa, Cirsium arvense* and *Vulpia octoflora*.

Species	Variable	Functional type P-value	Nativeness P-value	Interaction P-value
Bromus	Above ground biomass	0.83	0.001*	0.347
	Number of Leaves	0.536	0.005*	0.579
Achillea	Above ground biomass	0.001*	0.168	0.151
	Below ground biomass	0.014*	0.361	0.009*
	Number of leaves	<0.0001*	0.007*	0.0004*
Vulpia	Number of leaves	0.531*	0.459	0.023*

For *Bromus*, global ANOVA identified significant differences for above ground biomass and number of leaves (Table 25). The two-way ANOVA indicated that more leaves were produced when grown with noxious species (Table 26). This was especially evident when grown with *Cirsium*. A significant nativeness effect was also observed for above ground biomass measurements (Table 26); again, higher when grown with noxious species. No significance in height or below ground biomass was identified (Figure 50).

For *Vulpia*, global ANOVA identified significant differences for number of leaves (Table 25). There was an interaction effect for number of leaves (Table 26); specifically, above-ground biomass was higher when grown with functionally different noxious species. No significant findings were identified for spikelet number, spikelet mass, height or biomass (Figure 52).

Global ANOVA identified no significant differences for any of the variables for *Cirsium* (Table 25), nor were there any noticeable trends in the data (Figure 51).

Significant differences occurred in growth of some variables for all species when contrasted with the growth of control species (grown with no other plants). Some of the significant results occurred because of intraspecific competition while others occurred due to interspecific competition.

Significant intraspecific interactions were observed for *Bromus* and *Vulpia*. Significant variables for *Bromus* included less above-ground biomass ($F = 6.27$, $p = 0.0161$), less below ground biomass ($F = 4.39$, $p = 0.0420$), and although not quite significant, fewer leaves ($F = 3.76$, $p = 0.0589$). The significant intraspecific variable for *Vulpia* was lower spikelet mass ($F = 7.65$, $p = 0.0096$).

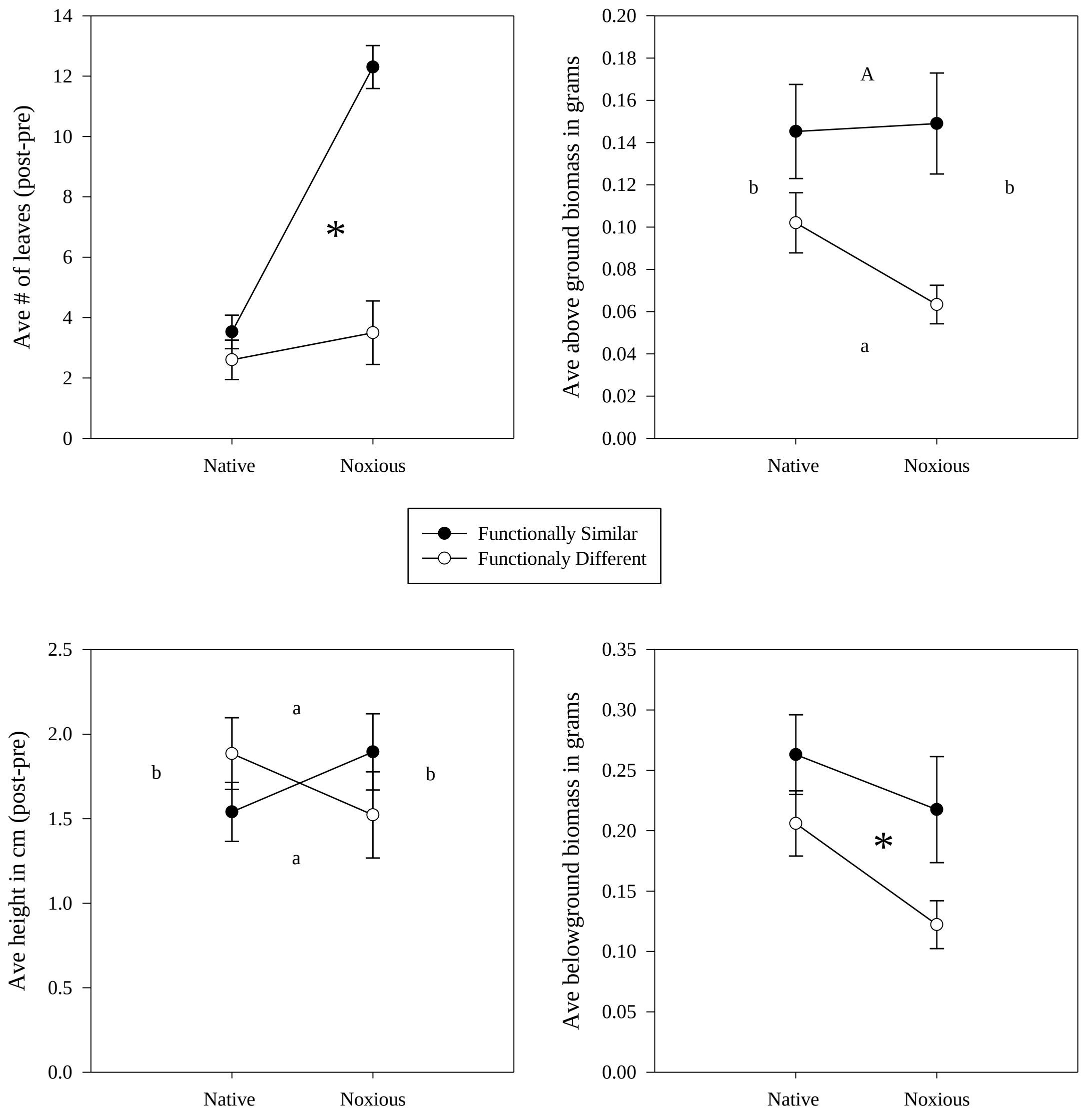


Figure 49. Interaction graphs for the effects of nativeness and functional equivalence on the means of a number of growth parameters for *Achillea millifolium* var. *lanulosa*. Circles denote cell means for functionally equivalent species(open circles) or functionally different species (filled circles), and vertical segments extend over ±1 standard error. Letters indicate significant differences between variables. Asterisks indicate a significant interaction between variables (two-way ANOVA).

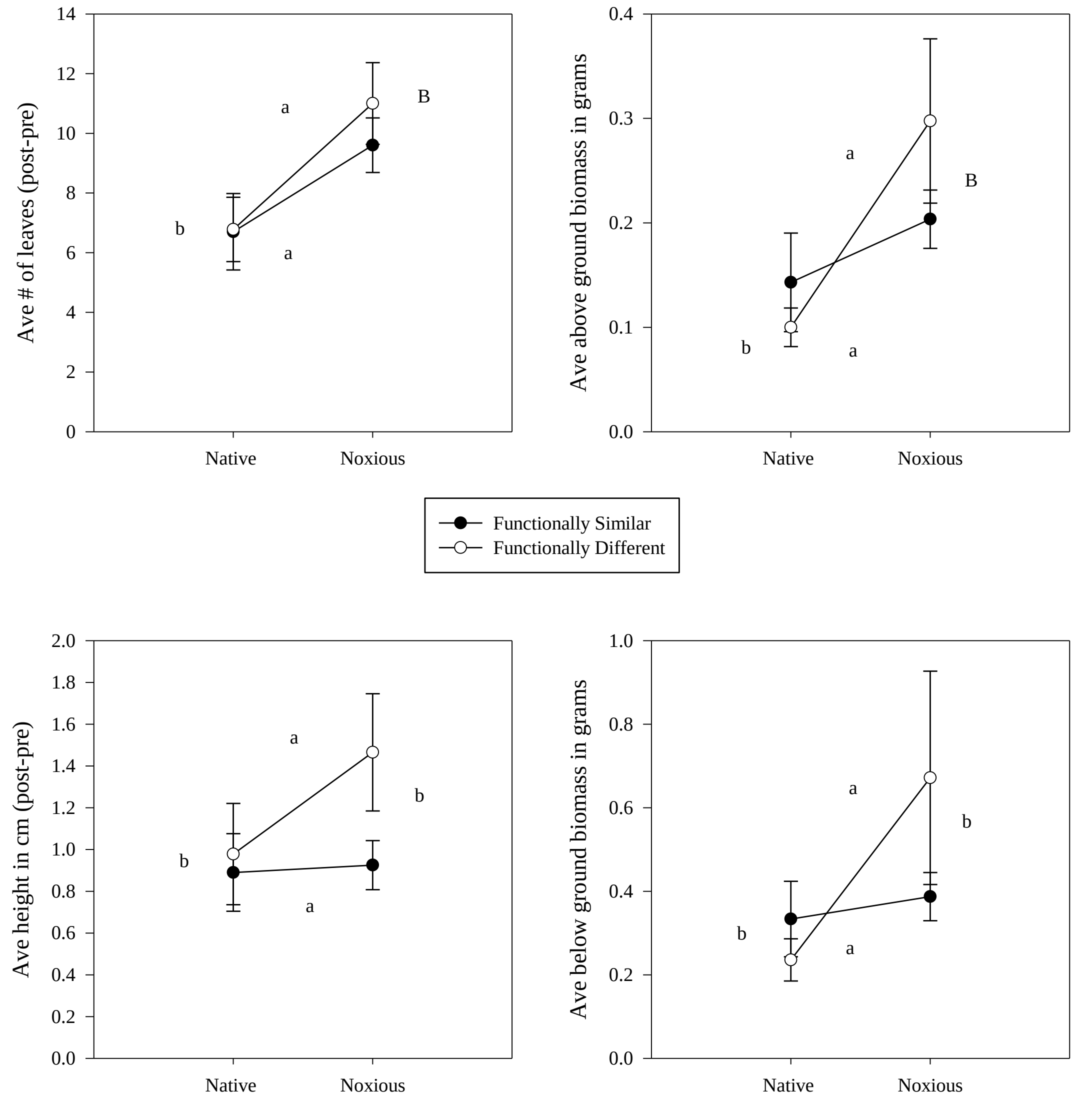


Figure 50. Interaction graphs for the effects of nativeness and functional equivalence on the means of a number of growth parameters for *Bromus tectorum*. Circles denote cell means for functionally equivalent species(open circles) or functionally different species (filled circles), and vertical segments extend over ±1 standard error. Letters indicate significant differences between variables. Asterisks indicate a significant interaction between variables (two-way ANOVA).

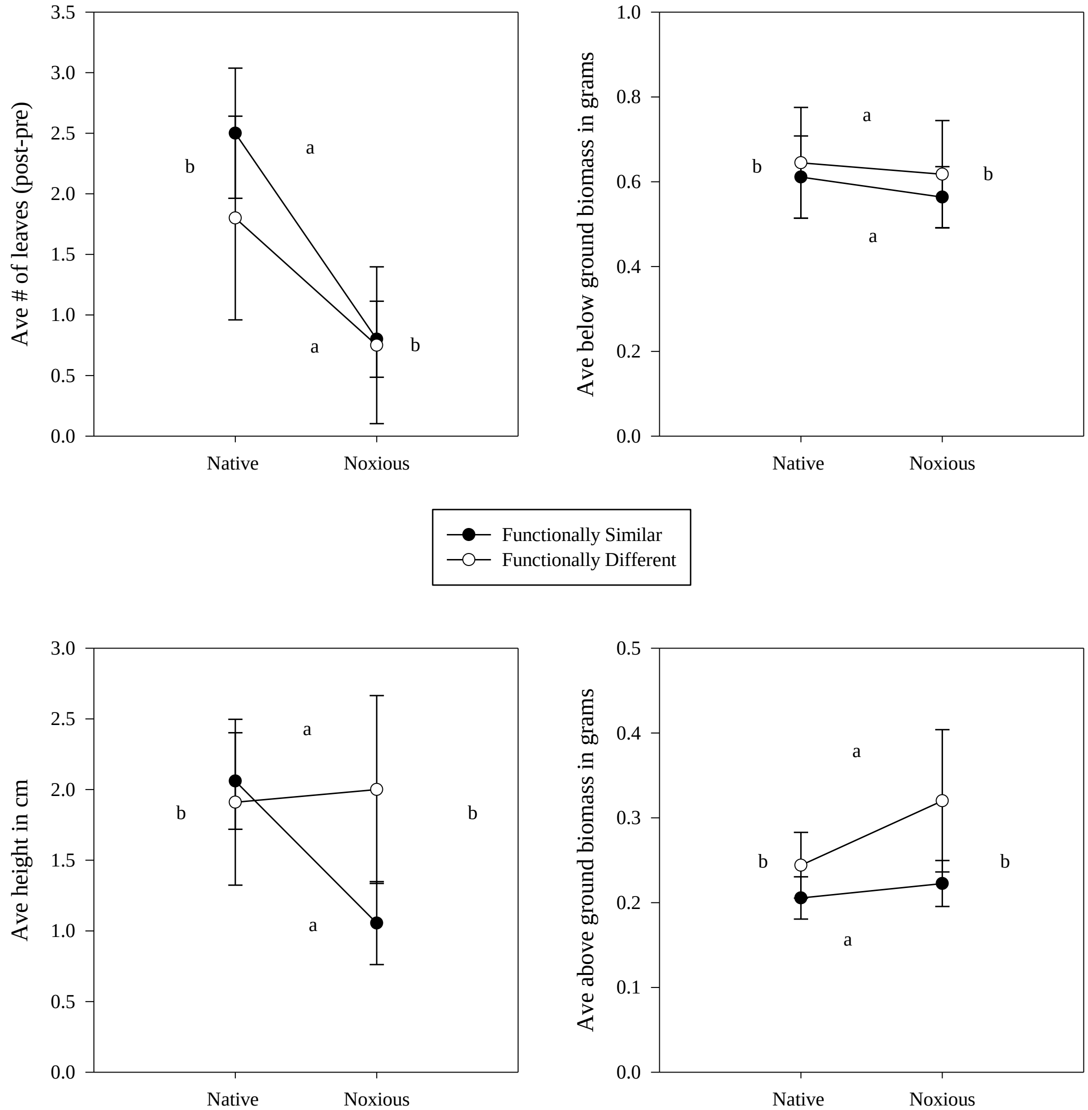


Figure 51. Interaction graphs for the effects of nativeness and functional equivalence on the means of a number of growth parameters for *Cirsium arvense*. Circles denote cell means for functionally equivalent species(open circles) or functionally different species (filled circles), and vertical segments extend over ±1 standard error. Letters indicate significant differences between variables. Asterisks indicate a significant interaction between variables (two-way ANOVA).

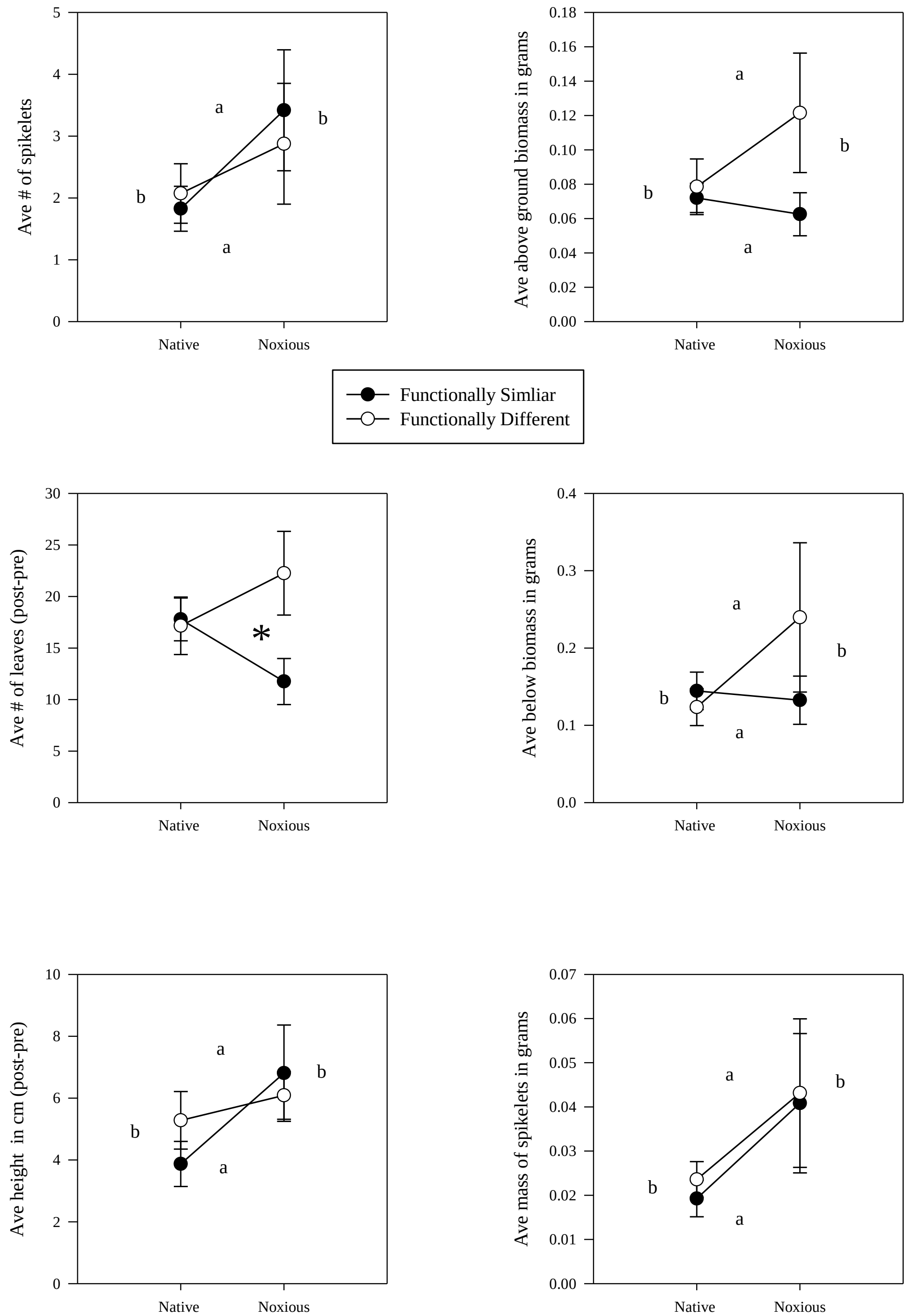


Figure 52. Interaction graphs for the effects of nativeness and functional equivalence on the means of a number of growth parameters for *Vulpia octoflora*. Circles denote cell means for functionally equivalent species(open circles) or functionally different species (filled circles), and vertical segments extend over ±1 standard error. Letters indicate significant differences between variables. Asterisks indicate a significant interaction between variables (two-way ANOVA).

Significant interspecific interactions for *Achillea* occurred with a greater number of leaves produced when grown with *Cirsium* (F = 23.50, p < 0.0001) and less above (F = 7.36, p = 0.0095) and below ground (F = 14.22, p = 0.0005) biomass when grown with *Bromus*. *Bromus* displayed interspecific significance with fewer leaves produced when grown both with *Vulpia* (F = 15.18, p = 0.0003) and *Achillea* (F = 10.94, p = 0.0019). Above-ground biomass and below-ground biomass showed similar significance with above-ground biomass being less when grown with *Vulpia* (F = 20.59, p = <0.0001) and *Achillea* (F = 24.43, p = <0.0001) and below ground biomass again being less with *Vulpia* (F = 10.18, p = 0.0026) and *Achillea* (F = 14.65, p = 0.0004). *Cirsium* only showed significant interspecific competition for number of leaves when grown with *Bromus*; with a decrease in number of leaves (F = 5.42, p = 0.0245). *Vulpia* demonstrated significant interspecific competition with fewer leaves F = 9.55, p = 0.0035) and lower above-ground biomass (F = 5.62, p = 0.0223) when grown with *Bromus* and lower spikelet masses when grown with *Achillea* (F = 4.08, p = 0.0525).

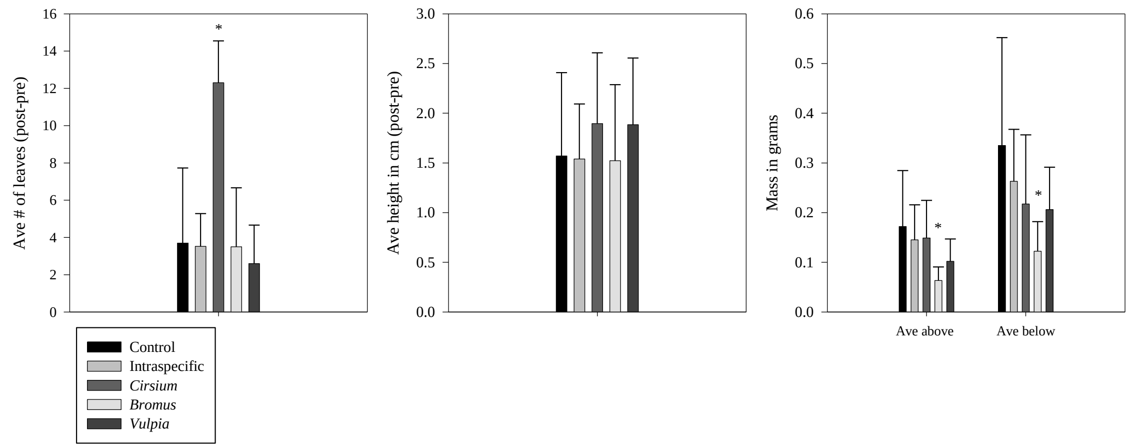


Figure 53. Control compared to intraspecific competition and interspecific competition for *Achillea millifolium* var. *lanulosa*. Black vertical bar in each graph is the control. Asterisks represent statistical differences from the control. Error bars represent standard deviations.

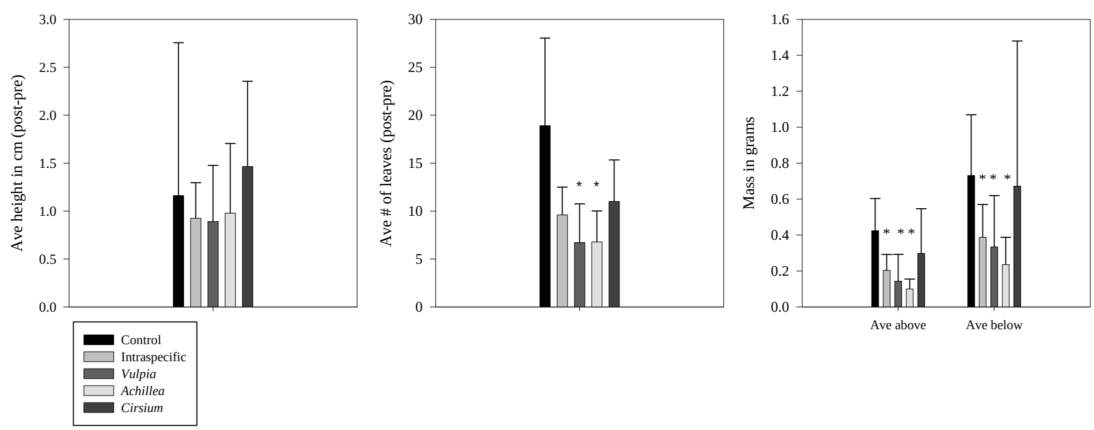


Figure 54. Control compared to intraspecific competition and interspecific competition for *Bromus tectorum*. Black vertical bar in each graph is the control. Asterisks represent statistical differences from the control. Error bars represent standard deviations. All data were log transformed.

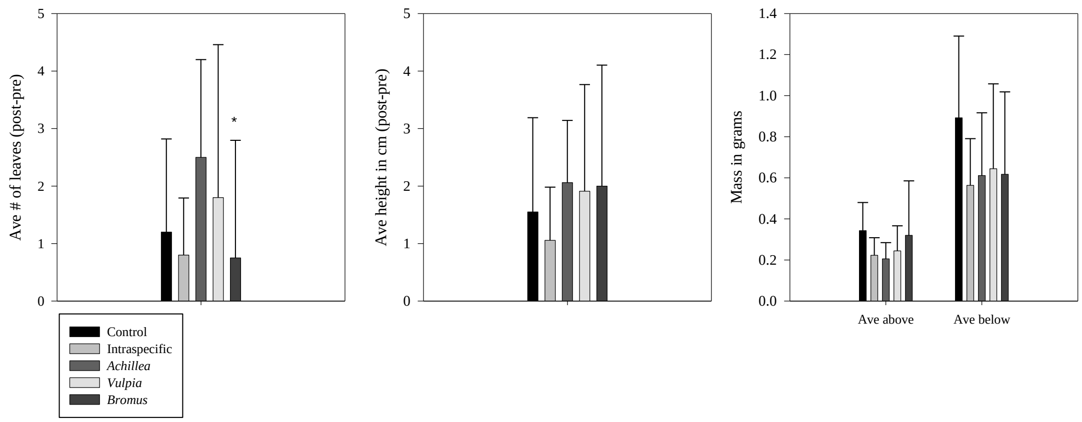


Figure 55. Control compared to intraspecific competition and interspecific competition for *Cirsium arvense*. Black vertical bar in each graph is the control. No statistical differences were determined from the control. Error bars represent standard deviations.

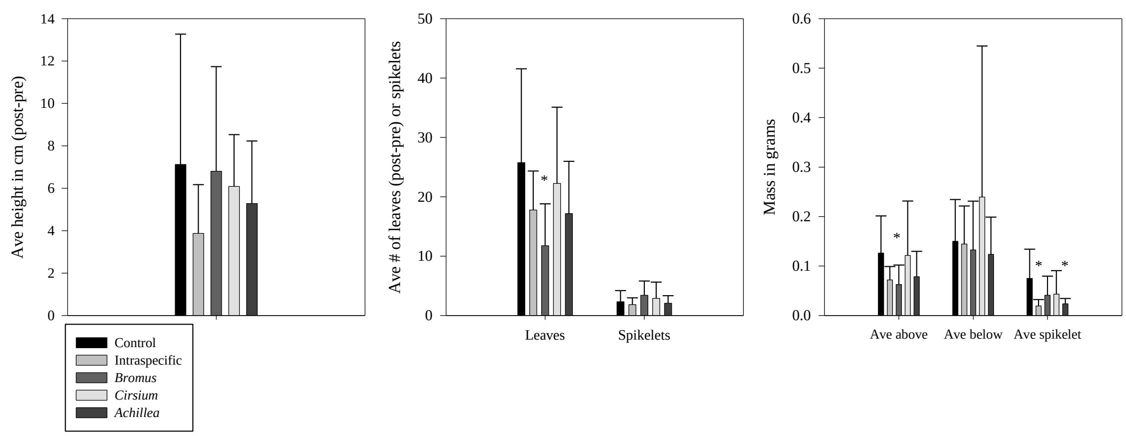


Figure 56. Control compared to intraspecific competition and interspecific competition for *Vulpia octoflora*. Black vertical bar in each graph is the control. Asterisks represent statistical differences from the control. Error bars represent standard deviations.

Field Study: Determination of Cirsium arvense competition in situ

Control and competition paired plots were similar in species percent cover prior to removal of vegetation in the control plots (Figure 57) (MRPP: T-value = 1.44, p = 0.957). All measured growth variables at the termination of the experiment were greater [albeit not all significant] in the plots where vegetation was removed (control plots). Both above-ground biomass and number of leaves were significantly greater in control plots (Table 27, Figure 58).

A steady increase in the number of leaves was observed over time, but much greater for the control plots where vegetation was removed after one week. For competition plots, the increase in leaves nearly stabilized after week four. Longest leaf measurements diverged from each other after one week and continued to become more different, but not significantly different, after week four. After week 4, leaf length stabilized in both the control and experimental plots. Height was greatest in the competition plots until the fifth week when the control became taller, although not significantly. Flower structures were present in the competition plots by the third week of the experiment but were not recorded in the control plots until week four. The increase in flower structures continued through week eight in the control plots but leveled off after week five for the competition plots (again, not significant; Figure 59).

Significant correlations were noted for above ground biomass, height, number of floral structures, and number of leaves of *Cirsium* in experimental plots in relationship to the percentage of forbs or graminoids present in the plots (Figure 60). For aboveground biomass, a decrease was noted as graminoid percent cover increased (F-value = 8.97, T-value = -3.00, p = 0.0201). This same trend was observed for *Cirsium* height (F-value = 9.81, T-value = -3.12, p = 0.0165) and number of floral structures (F-value = 16.95, T-value = -4.12, p = 0.0045). A significant increase in average number of leaves was seen as percent forb cover increased (F-value = 6.34, T-value = 2.52 p = 0.0399). In general, an increase in graminoid ground cover or decrease in forb ground cover contributes to poorer growth for *Cirsium arvense*. Composite species percentages for the experimental plots showed *Elymus smithii* to be the most abundant grass and other *Cirsium arvense* plants to be the most abundant forb (Figure 61).

For plants that experienced flooding, no significance was determined between the recovery of plants in treatments plots compared to control plots (Fisher's exact test, Left sided pr = 0.83; p-value = 1.0).

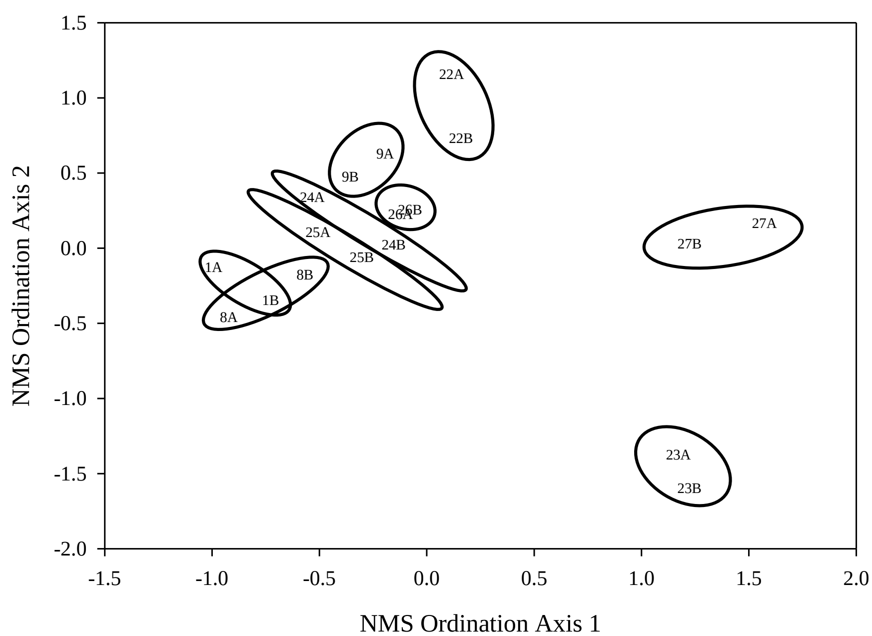


Figure 57. Ordination of the species percent ground cover of each plot. Circles indicate paired plots.

Table. 27. Paired-T test results comparing *Cirsium* plants grown alone (control) and *Cirsium* plants grown with competition, Weld County, Colorado.

Variable	T- Value	P – value
Above ground biomass	-4.56	0.0019
Height	-1.45	0.1839
Longest leaf	-1.97	0.0837
Number of inflorescences	-2.01	0.0798
Number of leaves	-10.62	<0.0001

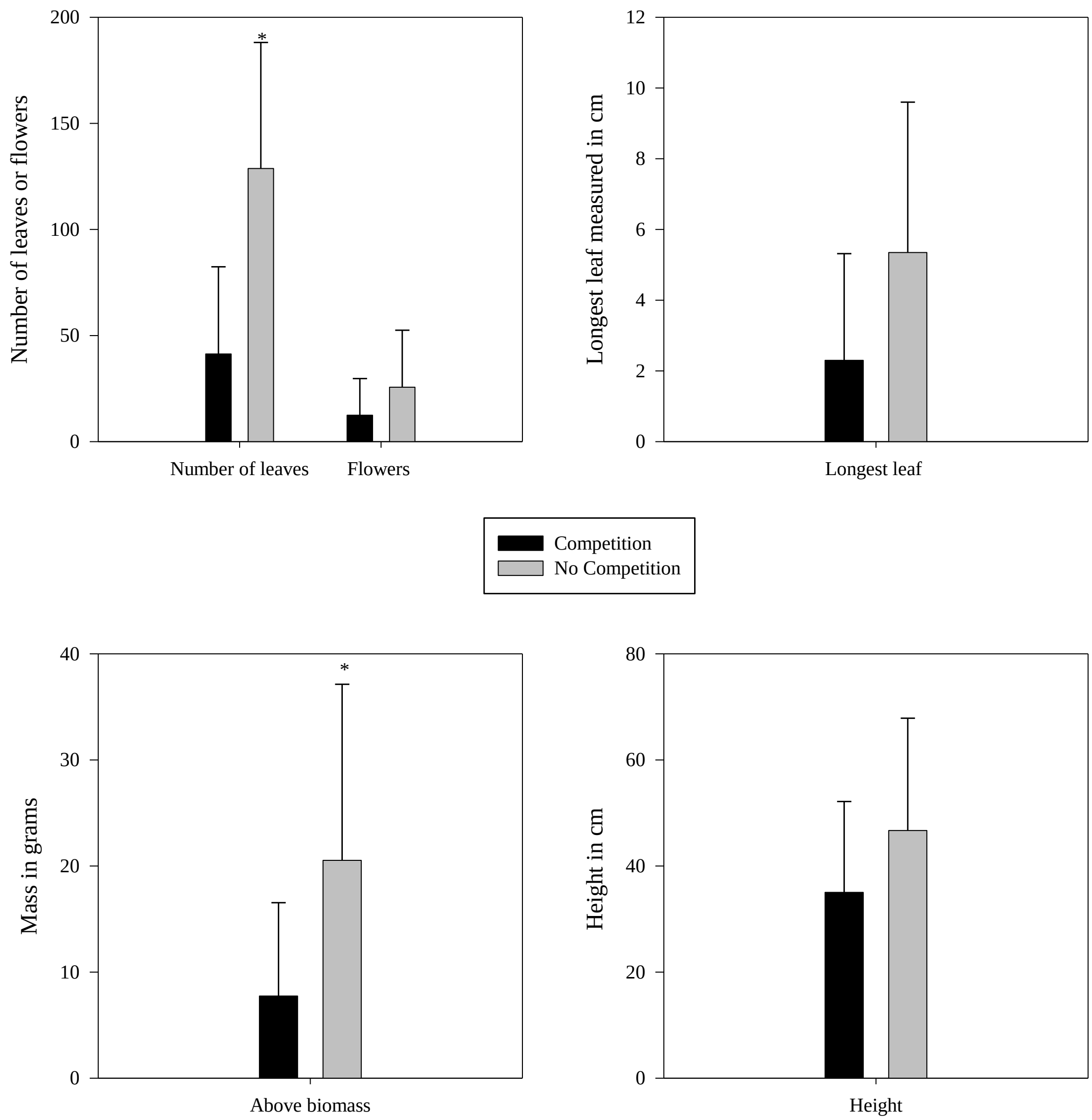


Figure 58. Growth parameters of *Cirsium arvense* grown with competition and without competition. Weld County, Colorado. Asterisks indicate significant differences.

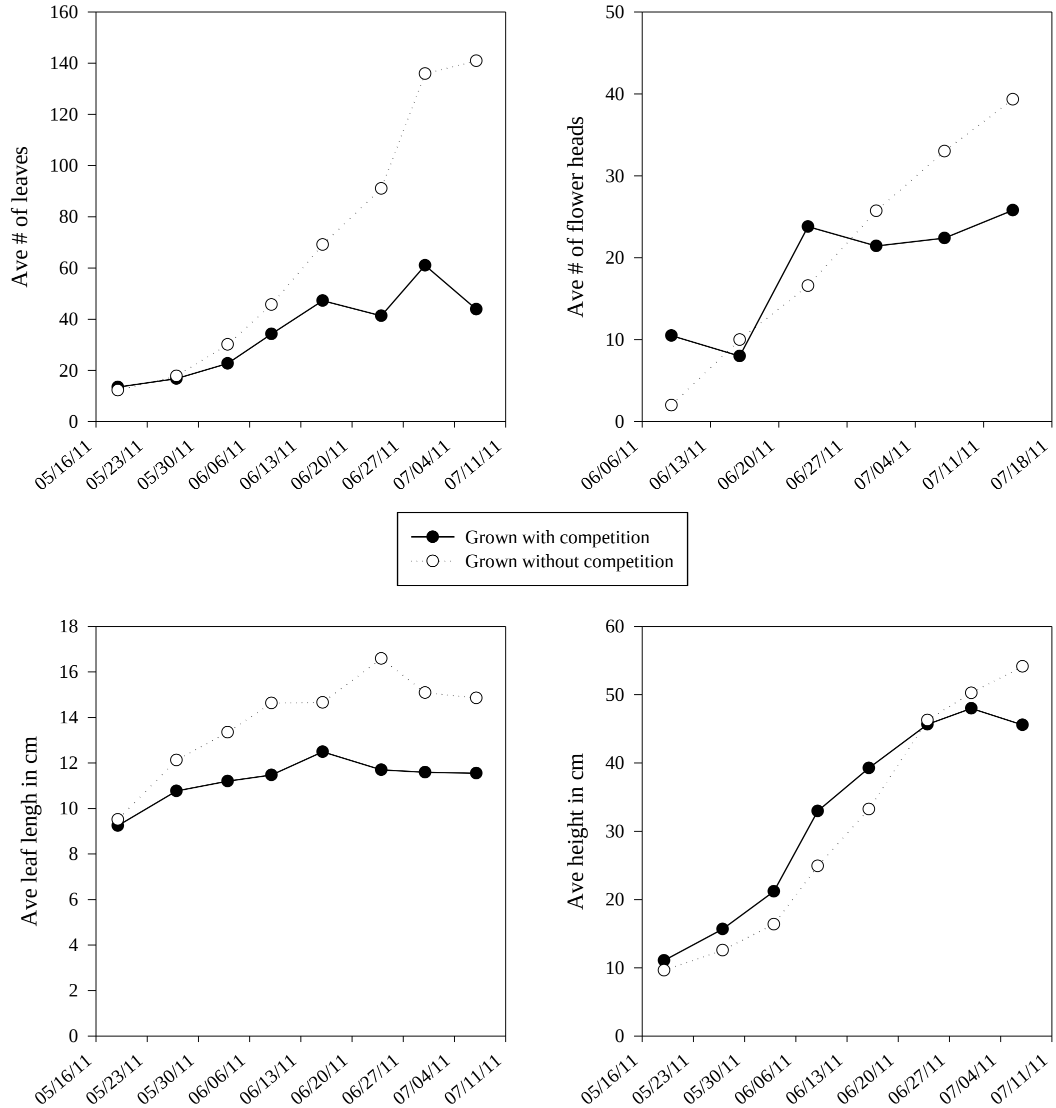


Figure 59. Change in the average measurements of the growth variables longest leaf length, height, number of leaves, and flower structures for *Cirsium arvense* in the field, Weld County, CO.

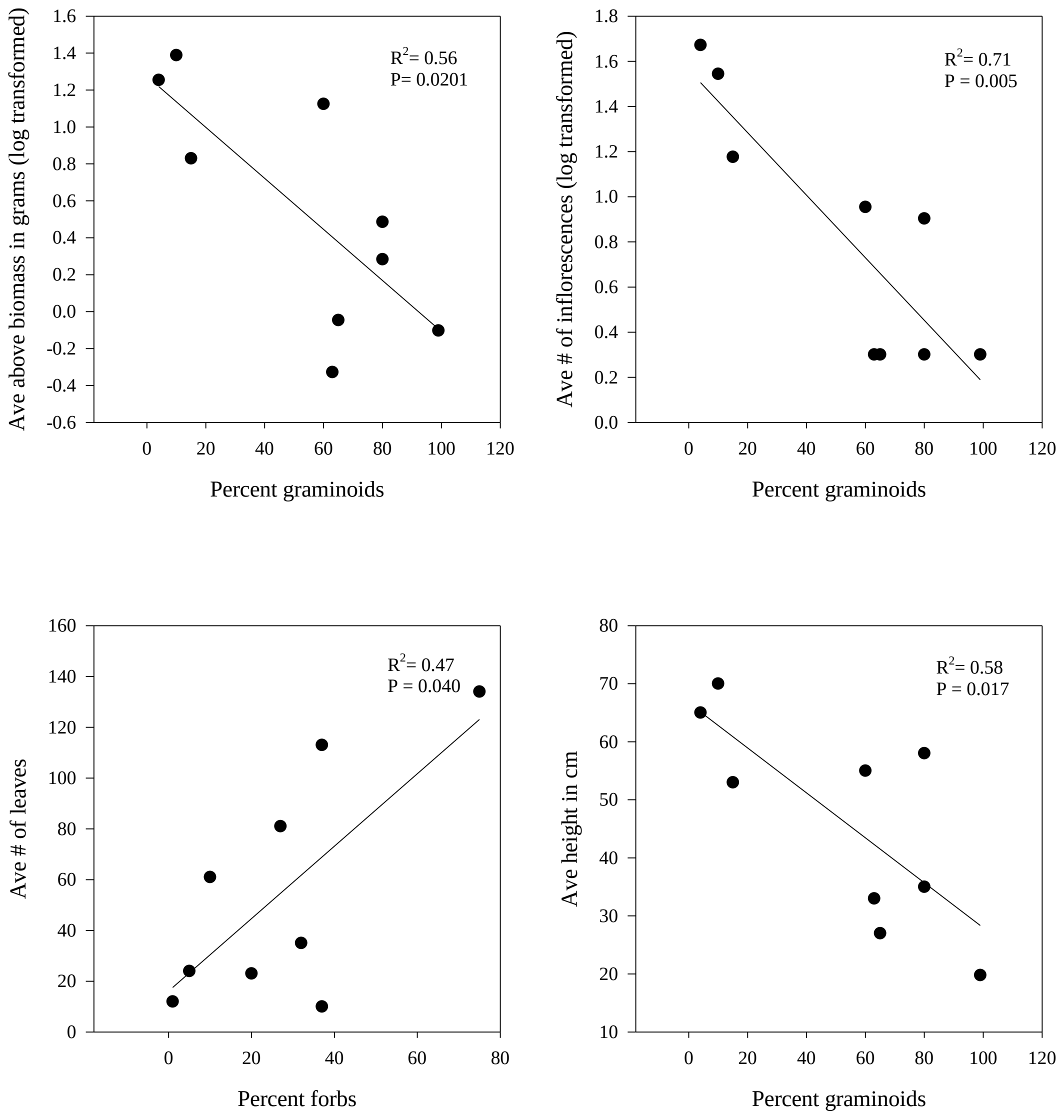


Figure 60. Significant variables identified through regression analysis predicting *Cirsium arvense* growth and flower production.

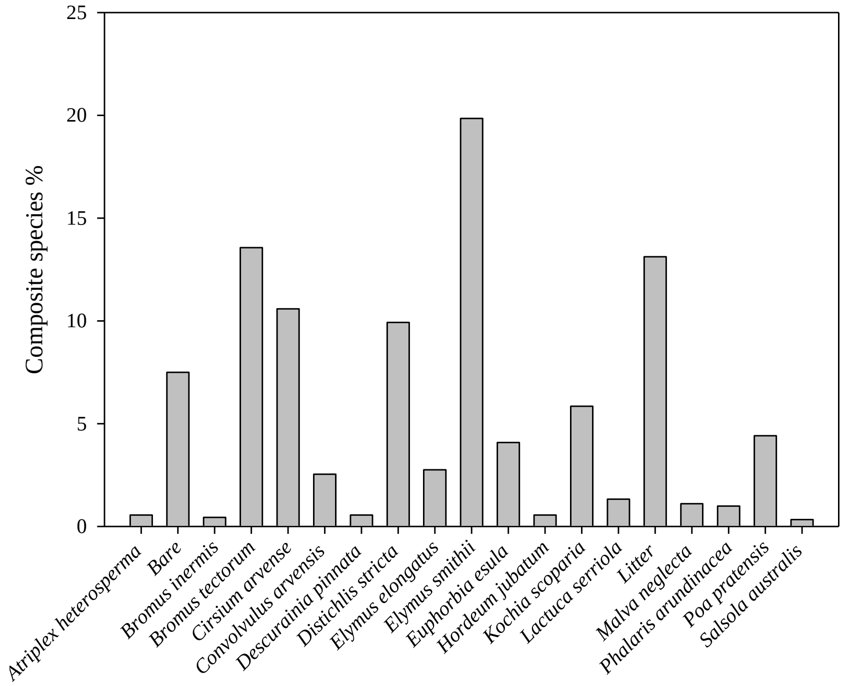


Figure 61. Composite calculations percent species cover for competitive plots used in the regression analysis.

Discussion

Competition increased with increased density for *Achillea*, *Cirsium* and *Vulpia*. When plants were grown at the 2 x 2 or the 3 x 3 density level, fewer leaves were produced. Therefore, hypothesis 1, "competition will increase with increased plant density," was supported fro these species. *Bromus*, however, did not show a significant decrease in number of leaves when grown at different density levels. Increased density typically increases competition (White & Harper, 1970), but certain plants are better able to tolerate crowding than others, especially if they display a high degree of plasticity (Harper & Gajic, 1961). *Bromus* did show similar trends of decreased leaf growth with increased density matching a previous study that demonstrated a density effect on seed mass for *Bromus*; the previous study suggested that its plasticity predicted its competitive success (Palmblad, 1968).

Hypothesis 2, "non-native species will grow better with native species than with non-native species," was rejected for *Bromus*. In fact, *Bromus* grew significantly better when grown with noxious plants. *Cirsium* demonstrated a competitive response to natives although not siginifcant. For example, it grew more leaves when grown with natives indicating a positive growth response but also grew taller and had less biomass indicating more resources were being utilized to grow above the natives (see below).

Some of the growth parameters seemed better indicators of competition than others. An increase in height did not seem to be an indication of less competition. Studies have shown that an increase in height is a response to increased levels of competition especially if the plants are competing for sunlight (Aphalo et al., 1999; Weinig, 2000). This is apparently what was observed in the *Cirsium* arvense grown in the field with competition. The competition group remained taller than the control for most of the experiment. Longest leaf was not a good indicator of competition for *Cirsium*, as the leaves did not continue to grow markedly in length over the course of the experiment; rather, leaf growth stalled out after week four. Above and below ground biomass, number of leaves, and number of floral structures all seemed to be better indicators of competition for the species we were investigating.

Hypothesis 3, "functionally equivalent natives will competitively inhibit functionally equivalent noxious weeds more than functionally different natives," was rejected for *Cirsium*. No significant decrease in growth was observed for any of the measured variables when grown with *Achillea*. *Cirsium* grew about the same in the greenhouse regardless of its neighbor. In the field, the hypothesis was also rejected; *Cirsium* showed a positive correlation when grown with other forbs. However, these forbs were typically not native. In fact, the most common forb associated with *Cirsium* in the field was other *Cirsium* plants and as noted in the greenhouse study, intraspecific competition was minor. Results from Bezemer et al. (2004) indicate that a seeded aster, *Tanacetum vulgare,* limited percent cover of *Cirsium* in research plots ; thus, it could be that *Achillea* is a poor competitor of *Cirsium* (see below), and examination of other forbs is warranted.

A negative correlation was demonstrated when *Cirsium* was grown with functionally different grasses. The decrease in number of flowers as the percent of grass increased showed a direct impact on fecundity. In some plots, these were perennial warm season grasses (*Elymus smithii* and *Disticalis stricta*), while other plots had a perennial cold season grass (*Poa pratensis*) or an annual cold season grass (*Bromus tectorum*). Future studies could elicit which of these species most effectively hinders *Cirsium* growth and fecundity. Our greenhouse study using biomass data indicates it is not *Bromus tectorum*. All of the perennial grasses in the field were rhizomatous, and perhaps in terms of functional classification, below ground structure of these rhizomatous grasses is more similar to *Cirsium* than *Achillea*'s root structure. Much plant competition occurs underground (Casper & Jackson, 1997). Other studies have shown similar inhibitory effects of rhizomatous grasses on *Cirsium* (Ang et al., 1995). Correctly identified functionally equivalent plants may also inhibit *Cirsium* growth as demostrated by a 1% decrease in growth when grown with the forb *Medicago sativa* (alfalfa) in an agricultural setting (Hodgson, 1968).

Noxious weeds had no impact on *Achillea*. In fact, it grew better when it was grown with its functionally equivalent supporting the notion above that *Achillea* and *Cirsium* may not be a functionally equivalent. As well as refuting our hypothesis that functionally similar species would inhibit growth more than functionally different species. For the grasses there appeared to be trends supporting this hypothesis, but none were significant.

For *Bromus*, the native species *Vulpia* did inhibit growth in support of our hypothesis but this inhibition was also noted for *Achillea*. The decrease was noted for three different variables including number of leaves, aboveground biomass, and belowground biomass. A previous field study found a decrease in *Bromus* when grown with a perennial grass (Thacher et al., 2009b), suggesting both perennial and annual native grasses compete with *Bromus*. It should be noted that *Vulpia* also showed decreased growth when grown with *Bromus*.

Hypothesis 4, “significant intraspecific competition will occur,” was accepted for *Bromus* and *Vulpia*. For *Bromus*, a decrease in biomass was noted which supports results from a previous study (Blank, 2010). Other variables for these species did not indicate intraspecifc competition. Neither *Cirsium* nor *Achillea* demonstrated intraspecific competition. Perhaps because perennials grow slower than annuals (Pitelka, 1977; Garnier, 1992), the greenhouse study did not offer enough time for the competitive effect to be observed.

It appears a number of different invasive strategies are being demonstrated by *Cirsium* on the shortgrass steppe: ability to utilize resources not currently being utilized in a community, adaption to disturbance, low species richness of the invaded community, and high level of propagule pressure, but none of these strategies were directly tested in our study. Its extensive root system which can extend 2-3 m is likely obtaining resources not utilized by local plants. In the field, *Circium* took advantage of the disturbance caused by gravel mining and agriculture. Results from plot data indicate low diversity of species surrounding *Cirsium;* this coupled with high propagule pressure (average of 30 inflorescences/plant from our study) predicts continued presence of the species. These factors support both the propagule pressure and species diversity hypotheses. *Cirsium* does not appear to be well-adapted to all areas on the steppe; rather, it is predominantly restricted to riparian and roadsides (Kotanen et al., 1998) indicting it is not drought tolerant.

For *Bromus*, invasive strategies, although not directly tested, likely include the ability to utilize resources not currently being utilized in a community, possession of novel traits with which to interact with the environment, adaption to disturbance, species richness of the invaded community, and level of propagule pressure. Being allelopathic may give *Bromus* a competitive advantage (Holzsapfel et al., 2010), but this was not observed in the greenhouse. In addition, it exhibits characteristics typical of an r-strategists which allows it to thrive in disturbed areas although it also is prevalent in relatively intact regions on the shortgrass steppe (personal observation). Its plasticity (Rice & Mack, 1991), drought tolerance, and early season growth (Chambers et al., 2007) allow *Bromus* to take advantage of spring precipitation and snowmelt common in eastern Colorado to ensure its continued presence.

The growth conditions in the greenhouse with daily watering, was atypical for upland conditions on the shortgrass steppe. Riparian areas will have more soil moisture than the uplands but not the regularity of water prescribed in our experiment. A future study should be conducted that investigates competition of these species under varying water levels to determine if any of them would have competitive advantages under greater moisture stress. Other limitations to the study included small sample size. For both the greenhouse studies increasing the sample size is recommended. In addition including competition between more than two species would better replicate the complexity of plant interaction in the field.

Management Recommendations

Overall, more research should be conducted to determine other native species competitive potential against these noxious weeds. Perhaps native forbs other than *Achillea* would inhibit the growth of *Cirsium*. Revegetation in general should be encouraged in disturbed areas and areas infested with noxious weeds, as vegetation cover was shown to decrease the prevalence of *Cirsium*. In particular, continued planting of perennial grasses is a good strategy on the shortgrass steppe for mitigating the negative effects of *Cirsium arvense*. Our results indicate *Vuplia* and *Achillea* could be used to lessen the impact of *Bromus*. We recommend experimenting with seeding these species in areas invaded with *Bromus* to determine there effectiveness in the field.

CHAPTER V

ASSESSING CHANGES IN PERCPTION AND UNDERSTANDING OF STUDENTS TOWARD MINE RECLAMATION SITES THROUGH AN EXPERIENTIAL PROCESS

Abstract

One of the goals of environmental education is to develop in students an understanding of the natural world, the impact humans have on the natural world, and the processes to mitigate human impact. Through this learning process it is desired that students gain an eco-consciousness that develops into a desire to impact the natural world in a positive way. To make a successful transition toward eco-consciousness students must understand destructive human impacts on the natural world and perceive the need for intervening through the process of restoration and reclamation to improve the condition of an impacted area. It is expected that direct experience will enhance the understanding and heighten the perception of the importance of these intervention processes. Through a case study I investigated understanding and perceptions of high school geology students toward aggregate mining prior to and after a visit to a gravel mine reclamation site. Fifteen high school geology students were involved in this study and participated in pre and post reclamation site drawings taking about ten minutes each. They also participated in pre and post site visit interviews lasting about seven minutes. Through this process misperceptions about mine reclamation were determined and the impact of experientially visiting a mine reclamation site was evaluated. Six underlying themes were found: increased interest in the issue of reclamation, increased knowledge of the mining process, sense of connection to site, articulation of the importance of reclamation, decreased emphasis of an anthropocentric purpose of mine reclamation and increased understanding of the structural composition of a gravel mine reclamation site. These results indicate the importance in place-based education for developing student understanding of science concepts and stewardship perspectives.

Introduction

It used to be a tranquil meadow covered with waving grasses and flowers, a gentle warm breeze could be felt and the smell of the clover drifted in the air. Now shrill grating sounds pierce the air, large earth moving vehicles gouge the soil; crunching rock dust and the nauseating smell of exhaust is in the air. The above describes the change that occurs to a natural environment through the process of gravel mining in Colorado. What will this area be like in the future? How does the environment respond to the impact of aggregate mining, and what is the process of returning it back to a functioning ecosystem through reclamation? In this study I evaluated understanding and perception changes occurring in high school students. The purpose of this case study was to discover the change in perception of high school students prior to and after to being exposed to a reclaimed gravel mine on the shortgrass steppe. Through this process potential student misperceptions about mine reclamation were determined and the impact of experientially visiting and interacting with a mine reclamation site was evaluated. A goal of the study was to evaluate interventions used at the reclamation site to enhance student understanding of the process and importance of gravel mine reclamation. The research question was, “How does a student’s interaction with a gravel mine reclamation site impact their perceptions and ideas of mine reclamation?”

As urbanization continues to encroach on natural land, more and more areas will be in need of, and benefit from reclamation. Individuals generally are unsure of or have negative ideas about the impact of mining on natural environments (Bloodworth et al., 2009). They have even less understanding of the importance and process of reclamation and how an environment changes through reclamation. Gaining an understanding of students’ perceptions will allow teachers in the future to develop teaching methods to more effectively communicate how reclamation benefits a disturbed environment. In addition, students themselves will apply direct experiences to develop an understanding of the importance of reclamation in their communities. This information can then be applied as students make decisions in the future (NAAEE, 2004).

Mining and construction are important and needed components to our industrial society and yet have great negative impacts on the natural world. This impact is seen through removed topsoil, chemical leaching, soil erosion, and loss of habitat. Many states including Colorado have requirements to mitigate the destructive impact of mining. The importance of reclamation from aggregate mining is taken seriously in Colorado and certain legal requirements must be met as noted in the Colorado Land Reclamation Act for the Extraction of Construction Materials, article 32.5, 2008 (Assembly, 2008). In this document, reclamation was defined as,

> the employment, during and after an operation, of procedures reasonably designed to minimize as much as practicable the disruption from an operation and provide for the establishment of plant cover, stabilization of soil, protection of water resources, or other measures appropriate to the subsequent beneficial use of the affected lands (p. 4).

The Act further clarifies the requirement of vegetation reclamation,

> In those areas where revegetation is part of the reclamation plan, land shall be revegetated so that a diverse, effective, and long-lasting vegetative cover is established that is capable of self-regeneration and is at least equal, with respect to the extent of cover, to the natural vegetation of the surrounding area. Species chosen for revegetation shall be compatible for the proposed post-extraction land use and shall be of adequate diversity to establish successful reclamation (p. 16).

Ecosystems impacted by these processes will not return to a natural state in a timely manner without reclamation (Langer & Arbogast, 2002).

Although students have been found to have a general idea of how human impact affects a natural site (Yow, 2008) this is the first study describing how students' perceptions change in response to experiencing an aggregate mine reclamation site. In a previous study, students have demonstrated misconceptions toward natural objects (Dove et al., 1997). One way to mitigate these misconceptions is through experiential activities, which have been shown to change an individual's perspective and understanding (Dewey, 1938; NAAEE, 2004). Lack of outdoor experience has contributed to some of the challenges facing youth today (Louv, 2005), and for that reason, there has been a push to involve students in outdoor activities to give them a sense of place and appreciation for nature. As environmental educators develop in students an understanding of the natural world there is also a hope that students will gain a desire to positively impact the natural world. To make successful transitions toward eco-consciousness, students must understand destructive human impact on the natural world and perceive the need for intervening through the process of restoration and reclamation to improve the condition of an impacted area. It is expected that direct experience will enhance the understanding and heighten the perception of the importance of these intervention processes. Generally, students are receptive to outdoor education and have a positive attitude toward it (Smeds et al., 2011). Through this study I assessed perceptions of students toward mine reclamation before an intentional experience with a mine reclamation site and evaluated potential changes in perception and understanding of aggregate mine reclamation after involving students in the experience of a mine reclamation site.

Methodology

Theoretical Perspective

The type of research I conducted was a case study (Merriam, 1998) in which I sought to understand perspectives and ideas students had toward reclamation. The case is bounded (Merriam, 1998) around the student's field trip to a gravel mine reclamation site, the PLC, and experiences occurring during this visit.

The epistemological perspective I approached this research from is one of constructivism (Cakir, 2008). Individuals develop meaning and understanding of their world and experiences through the building and creation of connections within their mind (Crotty, 1998). In the context of mine reclamation, students must put their experiences in the context of prior knowledge and experiences. When students are exposed to new ideas and activities that they have not experienced before, they must place these experiences in an already established frame work within their minds. The resulting new experiences will be constructed from the prior experiences. Students in this study showed a prior framework of perceptions and understanding of mine reclamation and after visiting a mine reclamation site, they constructed new ideas upon this prior framework. In some cases, misperceptions were changed and understanding reconstructed.

Researchers Personal Stance

Personally, I came into the study with certain perspectives and experiences. I have been trained as a biologist thus I have the perspective that a functioning ecosystem is one in which biodiversity and interactions are great within a biological community. I have also taught and interacted with high school students for over eight years and therefore have an opinion on their perspectives and prior knowledge. In addition I have been involved as an educator and researcher at the gravel mine reclamation site the PLC and most importantly have been involved directly with the reclamation occurring at this site and have a personal bias of the importance of reclamation.

IRB Procedure

An expedited IRB application was submitted and approved fall semester 2010. Data including both drawings and audio recordings are stored in a locked file cabinet in my office or on a password protected computer with only me having access to the data. Students' identities remained confidential. Consent forms will be stored for three years and then destroyed.

Participants

Fifteen high school students participated in this study. The high school is located in a moderately-sized city in the Front Range of Colorado. The students were typical of students enrolled in the geology class. Ten of the students were male and five of the students were female. Seven of the participants identified themselves as being Hispanic, three as Mexican, four as white and one identified themselves as being Latin. The age of the students ranged from 15 through 19 with the median age being 17. All of the participants lived either in town or in both town and the country. None of the participants identified themselves as living solely in the country. The representative sample selected represents the demographic profile for this school and more specifically for this geology class. The students were solicited for participation in this study through their geology teacher.

Setting

This research project became part of the geology curriculum dealing with mining and took place at three locations, the high school classroom, the room where interviews were conducted, and the PLC.

Figure 62. Photo used as a prompt for participants to complete reclamation drawing. (http://tommyersphotography.com/detail.asp?PhotoID=395&CtgryID=41&Child=False used with permission)

Entering into the classroom, the students were casual. They took a bit of time to quiet down. The pre interview drawing activity was presented to them to be completed based on a picture of an active gravel mine site (Figure 62) that was projected on a screen. The pre-interview drawing instructions were the following, “Draw a picture of what this area would look like after mine reclamation. Include as much detail as possible and fill as much of the paper as possible.” Students were given about five minutes to complete this task. Some of them started immediately, others took longer to get started.

After completion of this activity students who had agreed to participate in the study where then asked to go to one of two areas where the semi structured research questions were being asked (Pihlainen-Bednarik & Keinonen, 2011). The room I conducted interviews in was a conference-prep room with a table in the center as well as book cases and a copier located around the periphery of the room. Participants sat across the table from me and were asked a series of questions which were recorded utilizing the audio recording device on my computer. Alternately a research assistant conducted interviews in a prep/storage room, also sitting across from the participant, but in contrast to my interview room, it did not have a table separating the interviewer from the participant.

Two days after the pre-site visit interviews, on a mild October day with temperatures in the mid 60’s, the participants along with the rest of their class were brought to the mine reclamation site, the PLC. The PLC is located in Weld County, CO adjacent to the Cache la Poudre River (40°26'35" N latitude, 104 °48'55" W longitude) with an average elevation of 1437 meters. This site falls within the zone of prairie known as the shortgrass steppe and is typified by drought tolerant plants such as Blue grama (*Bouteloua gracilis*), Buffalo grass (*Bouteloua dactyloides*) and Prickly pear (*Opuntia polyacantha*); adapted to an average annual precipitation level of 260-375 mm

(Anderson, 2006). The site has experienced much degradation through agriculture, aggregate mining, and urbanization; gravel mining occurred from 1986-2003. Prior to mining, this area was a heterogeneous landscape consisting of 65 acres of shortgrass steppe, wetland, and riparian/terrace habitat (Resh & Chimmer, 2005). The influence of the Poudre River has provided some complexity to the site, allowing patches of taller grasses to occur in the year-round mesic conditions of the associated riparian areas. As is the case with many degraded landscapes, the PLC has experienced a greater abundance of noxious invasive weeds than undisturbed landscapes. Some of the more abundant invasive weeds found on site include cheat grass *B. tectorm*), Canada thistle (*Cirsium arvense*), white top (*Cardaria draba*), field bindweed (*Convolvulus arvesis*), leafy spurge (*Euphorbia esula*), smooth brome (*Bromus inermis*) and sweet clover (*Melilotus albus*).

Active gravel mining was terminated on the site in 2004. The removal of overburden (topsoil obtained from the mining site) which had been placed on the site was completed in 2006. An 18-acre augmented lake was created on the site and the topography was returned to a state similar to pre-mining. In 2006, the site was tilled and seeded with a twelve seed grass mix containing the following species: sideoats grama (*Bouteloua curtipendula)*, blue grama (*Bouteloua gracilis)*, alkaligrass (*Puccinellia nuttalliana*), alkali sacaton (*Sporobolus airoides)*, little bluestem (*Schizachyrium scoparium*), needle and thread (*Hesperostipa comata)*, switchgrass (*Panicum virgatum*), western wheatgrass (*Agropyron smithii*), Indian ricegrass (*Achnatherum hymenoides*), yellow Indiangrass (*Sorghastrum nutans*), prairie junegrass (*Koeleria macrantha*) and sand dropseed (*Sporobolus cryptandrus*) at a density of 8.2 kg/acre. The seeds were then covered with weed-free straw mulch to prevent soil erosion. No native forbs or annual species were included in the replanting efforts. The site has also been managed to control the invasion of noxious weeds through a combination of methods such as manual removal, mowing, and localized biological controls.

Prior to arriving at the PLC, students stopped at an active gravel mine and made observations about what the active gravel mine looked like. Once arriving at the PLC, students were brought into the classroom and asked to simulate the process of gravel mining and reclamation. Each group of students was given a tray containing three plant types (western yarrow (*Achillea millifolium* var. *lanulosa*, six week fescue (*Vulpia octoflora*), and cheat grass (*Bromus tectorum*)) growing in potting soil above a gravel and sand substrate. They were instructed to remove as much of the gravel resource as possible. After the removal of the resource they were then asked to reclaim their site by putting the vegetation back into the planting tray. Students appeared to be engaged in this activity and were actively participating with other members of their group. They approached the process of removing the gravel and in a number of ways. Some of them carefully removed the vegetation in large chunks and then proceeded to move the gravel and sand out of the trays. Another group removed plants individually, then removed the potting soil, followed by removal of the gravel and sand. One group left the vegetation intact and removed the sand and gravel by digging under the plants and potting soil.

Students were asked to reflect on and determine plant composition before and after this simulated activity. The intention of this reflection was to get students to visualize how the process of mining could impact vegetation structure and distribution.

Following the reclamation activity, a power point presentation was shown in which the word reclamation was defined. In addition, the history of reclamation of the site was presented in photos and included the removal of the overburden pile, digging of the meander scar, reseeding of the site with a native grass seed mix and covering these reseeded areas with straw mulch. Weed management being employed at the PLC was briefly described. After this presentation, students were brought outside to observe the site. Since it was late October, all of the plants were dormant (Figure 63). Students were shown where the artificial meander scars were created, where the overburden was and areas of the site that showed different progress in recovery of the native grasses that were planted. Students were also shown an area where a road had been taken out and a wet land area had been dug. In addition students were shown the augmented lake on site created from the gravel pit. Students were asked to make close observations of the vegetation present on the site.

Figure 63. Composition of ground vegetation at the Poudre Learning Center, Weld County, CO in the Fall.

Six days following their site visit, students were again asked to respond to the photo of a gravel mine site (Figure 62). They were given five minutes to complete their drawings and were again interviewed following the semi-structured script from before. In addition to the pre questions, near the end of the interview after students were asked if they knew of any local mine reclamation sites, students where asked how the trip to the PLC impacted their ideas about mine reclamation.

Analysis of Data

Following basic qualitative research methods (Merriam, 1998), the interviews were audio recorded, and transcribed. After transcribing the quotes, organizing observational notes and student drawings, formal analysis was initiated. The data were analyzed in an effort to identify major themes and salient quotes. Perception of change was evaluated by determining how the participants' answers and drawings changed from the initial visit to after the students experienced the reclaimed site (Shepardson et al., 2007). Five of the major themes are presented in this chapter. These themes included: increased interest in the issue of reclamation, increased knowledge of the mining process, sense of connection to site, articulation of the importance of reclamation, decreased emphasis of an anthropocentric purpose of mine reclamation and increased understanding of the structural composition of a gravel mine reclamation site.

Analyzing different data sources (interviews, observations and drawings) allowed triangulation to occur (Jick, 1979). In addition an independent researcher listened to all of the transcripts to verify its correctness. Through these processes the findings were corroborated. The above procedures ensured the study was valid and reliable.

Findings

Increased knowledge of the gravel mining and reclamation processes

From the pre interviews and pre site drawings, it was apparent that many of the participants did not have a good understanding about gravel mine reclamation. This misunderstanding was articulated through the following quote, "I don't know exactly what they do in mine reclamation." Others had a basic understanding of what reclamation was, but applied the process to subsurface mining such as copper mining. This was seen from a pre site visit picture where the participant drew a hole in the side of a mountain.

In response to the process of reclamation for pre site visit responses, many students included some of the processes involved in reclamation, but did not have a complete understanding of the process. Others felt reclamation involved the process of replacing animals with a correct balance of predator and prey species. "First turn over the soil making it fertile so grass and trees can grow maybe throw in some rabbits, we would need some wolves as well rabbits and trees."

After visiting the site, a more complete understanding of the reclamation process was articulated. Including the steps involved.

> First I would put in seed try to put everything back the way it was, maybe put in a lake. Or put in some trees. Maybe some grasses I'll try to find the same grasses that were there but in seed form and like plant them, replant them and then start moving out the equipment like the trucks and everything so that theywouldn't bother anything.

The above response was typical of the increased understanding of the multiple steps involved in reclamation.

Students included a lake in most of the post visit drawings and interviews. A lake would form from the hole created from removal of the gravel as articulated by one of the participants, “I like the lake, I put a lake there, like if there was a hole where we were digging and went lower I guess we could make it lower make a lake there.” Some of the pre site visit pictures showed water in the form of a river, which would not be the result of mining.

Vocalization of the importance of reclamation

Students gained the perspective of reclamation being an important process to occur and for a number of different reasons including preservation, use-ability, and recreation. From the pre visit questions and drawings it is apparent that some of the students felt that mining was beneficial. Others did not think it was beneficial or needed. For example participant three responded, “No because you own the land” to the question of if land should be reclaimed.

After the site visit, most students responded that reclamation would be helpful and felt it important to put the mined site back the way it was before. The following quote was a typical response, “Yes cause then you don’t have the whole chunk of land that’s not being used, you could use it for walking trails or something”. Although most participants felt mined sites should be reclaimed, there was one individual who felt reclamation should not occur and that a mined site should be fenced off for safety reasons. Interestingly, no students mentioned the need to maintain natural areas for future generations. Perhaps students of this age group have a difficult time thinking of future generations because they do not have children themselves.

Increased understanding of the structure of a gravel mine reclamation site on the shortgrass steppe

From the pre-field trip drawings, a number of objects were included in the drawings that would not be found on the shortgrass steppe. Most noticeably students included trees. These trees were both deciduous and coniferous and often dominated the landscape in these drawings. The ideas of trees being found in reclamation areas also came through in the interviews as noted from the quote that follows describing what a reclaimed area would look like, "Maybe like trees like more trees." Trees would not typically be located in the shortgrass steppe because of low levels of precipitation but are more common in urban areas. The only places deciduous trees would be found historically on the short grass steppe would be in riparian areas and although the PLC does have a few deciduous trees they are restricted naturally to areas around the wetland, lake, and river.

In the post site visit grasses became more dominant in their drawings and interviews. One participant described their drawing the following way,

> We could put grass or like weeds, these are like plants and there are like planted grass and these are rocks and little things there are rocks in there, this is overburden then there would be like some dirt over there and these are high grasses.

They were clearly describing the structural composition of the site being composed of a variety of grasses. It is also interesting to note that after the site visit, participants mentioned weeds being present on the mine reclamation site. Weeds are typical in areas of disturbance on the shortgrass steppe as in other disturbed areas (Vitousek et al., 1996).

In general, more non-tree plants were included in the post pictures including grasses, weeds, flowers and aquatic plants.

Participants correctly included in pre-site drawings animals that would be found on the shortgrass steppe including birds, deer, a snake, a fox, a fish and a rabbit. Some of the pictures included mountains. Different animals were included in the drawings after the visit, but would also be found on the shortgrass steppe or in water habitats including: birds, ducks, a butterfly, an owl, a mouse, fish and a snake.

Decreased emphasis of an anthropocentric purpose of mine reclamation

Many of the participants drew people and human built structures including houses, skyscrapers, playgrounds, roads, vehicles and a restroom in their pre-visit drawings. It is interesting to note that humans were also included in many of the pictures. The humans in these drawings were actively involved in some activity. For example, a human was hunting in one picture. In another picture humans were climbing a tree. Students had an anthropocentric view of the reclamation process prior to visiting a reclamation site. The following quote in response to the question of if reclamation is needed, articulates this human-centered perspective, “Yes I do because it is the ecosystem and it’s important for our environment and if we are going to do anything like for our use.” Clearly the focus is on how humans will benefit from the reclamation process.

Following the site visit, people were present in only one of the drawings. In addition, there was a noticeable decrease in human buildings when participants redrew what a reclamation site would look like. There was a shift toward reclamation being done to help nature. This idea can be seen from the following quote, “I think it is beneficial, not for us really, I guess it's good to live in a healthy environment but really it's just for the plants and animals".

Identification of a specific reclamation site location

Probably the most interesting piece of information to be gained from the pre interviews was the lack of knowledge about local reclamation sites. Some identified oil fields as going through the process of reclamation while most could not identify a gravel mine reclamation site nearby.

Following the site visit, students could define reclamation and also were aware of a mine reclamation site location. The following quote demonstrates this understand of place.

> we went and we go there cause the Poudre Learning Center before was a gravel mining place, but now there is a lake theres grasses and theres meander scar where the river used to run through now runs through a different place and they took moved it around and they planted new grasses in there still native grasses there but they planted new ones and they couldn't bring in dirt, more dirt in but they used the meander scar to take dirt over there and put it so that could like level it our or something

The above quote also demonstrates how participants included both in their drawings and interviews some site specific components of the reclamation occurring at the PLC. These site specific responses included the creation of artificial meander scares and removal of the overburden pile.

Increased interest to the issue of reclamation

This theme was determined by looking at the length and depth of the post interviews. In the post interviews, the participants had more elaborate answers and were able to describe the issue in more detail and also were able to connect restoration more to their experience. In describing if the site visit impacted his ideas about reclamation the participant replied, “yea cause we actually got to see it and see how it looks now that its been replanted and we saw some of the overburden and stuff.” Without a site visit, this participant would not have connected as much to the topic of mine reclamation.

Discussion - Recommendations

From this case study more specific understanding of gravel mining occurred. Participants saw the need and also were able to connect and use the experience to formulate a more complete understanding about gravel mine reclamation. High school students in general typically show a disinterest in learning about things that are not related directly to their lives. It was apparent for the pre interviews that the students did not have an interest and understanding about mine reclamation. They were not connected to the process and often had misconceptions about the process of mine reclamation and specifically about gravel mine reclamation. Much of their knowledge appears to have initially come from textbooks or videos. This perspective is intuitive from a constructivist perspective. Students can only build information upon prior knowledge and experience (Crotty, 1998).

The trip to the mine reclamation site had an impact on student understanding and knowledge of mine reclamation. Students where including specific reclamation procedures in their responses to questions after the site visit. They were talking specifically about the overburden removal and planting of grasses. Almost all of the individuals mentioned or included a lake in their post interviews and reclamation drawings.

A challenge still lies in the ability to get students to care and develop an environmental ethic (Mueller, 2011). There was a shift toward more ownership and involvement of the process of reclamation, but most students did not articulate a connection or passion for the process of restoration and reclamation. Developing a sense of connection and place is important to developing this environmental ethic, but somehow the curriculum must connect with students and their current interests. The process of visiting the mine reclamation site moved students in this direction, but did not completely motivate students to change their perceptions.

Not understanding the terminology appears to be a hindrance of building the connections needed to really grasp the process of mine reclamation. Even though most students could define the process of reclamation after visiting the reclamation site, they appeared to have stumbled with this word initially and seemed to understand it after it was defined, but many did not recognize the word even though it had been brought up in class on different occasions.

Four activities were conducted during the students visit to the PLC, they included, the gravel mine simulation, the power point presentation and the walk about the mine reclamation site. Other educators may want to utilize some of these activities in their classrooms. The power point presentation and the walk about appeared to have the most impact on students as material covered during these processes were brought up by the participants in both their interviews and drawings. None of the students brought up the mine reclamation simulation in their post interviews. One can conclude from this that that activity had little impact on their understanding of the process or that the interview questions did not address the learning that may have occurred through this particular activity.

The time of the year the study was conducted may have an impact on student's perception of mine reclamation. In October, the site does not appear as a green verdant meadow, rather it is composed of shades of brown and red (Figure 63), the taller grasses including western wheat grass, smooth brome and alkali sacaton are interspersed with some of the shorter grasses such as side outs grama and switch grass. Many of the forbs are difficult to identify this late in the season. Perhaps visiting the site in the summer during peak biomass would have given students a different perspective of the process of reclamation. Another limitation of the the study was the small sample size. Increasing the sample size beyond 15 students may have generated different themes. In addition, because the case study is bounded by the specific school, specific reclamations site and specific students, transferability of the results should not extend beyond this case.

Conclusion

From the above data, one can conclude that after the site visit participants had gained a more complete picture of the process of reclamation although some misperceptions still persist. Many students did not go into much detail concerning the benefits and purpose of reclamation. Students were able to gain a sense of place from this experience and that certainly contributed to their perceptions about the process. Students also shifted away from a human centered purpose for mine reclamation and included more broadly the natural world including plants and animals.

As human impact on the environment continues to increase, understanding how students think about these modified environments becomes critical in connecting with students and developing responsible stewards of the environment (Tsurusaki 2010). Some general recommendations concerning this topic include being explicit in teaching reclamation, giving students specific experiences at reclamation sites and relating directly to these sites when discussing the process of reclamation. To develop a sense of eco-consciousness it is necessary to talk about the importance of reclamation. Encouraging students to think about what would happen if mine reclamation did not occur may give them a perspective to consider the importance of the process. Give students an opportunity to experience a mine site as well as site going through the process of reclamation. The experience appeared to really solidify the connection to the topic. Identify themes related to reclamation that students can connect with. Maybe it will be anthropocentric, such as the importance mineral resources have for our society, or it could be to increase recreational activities and locales, or maybe connecting to the idea of the damage un-reclaimed sites confer to the environment.

This study indicates the importance of place based education in enabling students to make appropriate connections about mine reclamation. Development of other activities could be incorporated at the mine site which would broaden the understanding of the process and connect the students to specific plants being selected at the site and including these plants in the mining simulation would enable appreciation and care for nature to develop.

Future Directions

This research has opened up other questions that would be interesting to answer. For example, assessing long term participant understanding on this topic would be helpful in developing effective curriculum. Determining what is retained after 6 or 7 months would allow one to evaluate what parts of the activities really impacted the participants, subsequent activities could be developed to scaffold upon these themes.

Since all of the participants were from urban areas, determination if different background or experiences contributes to understanding of mine reclamation would be helpful. Maybe connections can be found that a different group of students might make that could be generally transferred to other learners.

It would also be interesting to delve deeper into how the participants formulated their knowledge and perceptions about gravel mine reclamation and to determine what contributes to their perceptions

CHAPTER VI

CONCLUSION AND SUMMARY OF RESULTS

Humans continue to have a profound impact on our natural world. This impact will increase as the population continues to increase. We are called as individuals and a society to make a difference and to minimize our impact so that future generations have the ability to enjoy a quality of life that is equal to that of previous generations. Conservation, restoration and education are important components to the process of ensuring that we leave planet earth better than how it was found. As Aldo Leopold said so eloquently,

> One of the penalties of an ecological education is that one lives alone in a world of wounds. Much of the damage inflicted on land is quite invisible to laymen. An ecologist must either harden his shell and make believe that the consequences of science are none of his business, or he must be the doctor who sees the marks of death in a community that believes itself well and does not want to be told otherwise (Leopold, 1949).

This concluding chapter will describe the main findings of this dissertation which may be used to mitigate the impacts of anthropogenic disturbances and serve as a conversation point for ways to engage individuals and students in the process of stewardship. From these studies, it is clear that the process of restoration can and does contribute to improving the quality of disturbed environments and that there are certain mechanistic controls for community response to disturbance. The studies examined the success of gravel mine reclamation, the response of vegetation to gazing and competition (mechanistic responses), and the efficacy of experiential environmental education.

Evidence of Restoration Success

Based on the nine restoration attributes the Society for Ecological Restoration recommends for assessing reclamation success (SER, 2004), the PLC is moving in the direction of full restoration. The PLC has less vegetative cover than the reference sites but does show 69% ground cover overall indicating that re-vegetation efforts have been successful (Ruiz-Jaen & Aide, 2005). Many of the species located on the PLC were different from the Pawnee sites, but there were several species which occurred in both sites. Nine species were shared by the PLC and by one or both of the Pawnee sites. Many of the native grasses planted during the reclamation process are established at the PLC. The community similarity analysis showed the PLC being more similar to one of the Pawnee sites than the Pawnee sites were to each other; and when the analysis was conducted based on functional types, the PLC was more similar to both reference sites than the reference sites were to each other. Thus, the PLC site falls within the range of variation for vegetation composition on the shortgrass steppe (Smith & Smith, 2001). When comparing the maximum and minimum ranges of the PLC plots to the Pawnee plots, the PLC plots are within the range of at least one of the Pawnee sites for the following characteristics: evenness, richness, diversity, soil nutrients, biomass measurements and amount of litter. Again this indicates that some of the plots at the PLC are within the reference conditions of plots on the Pawnee Grassland. A similar type of approach has been used in aquatic systems to determine health of the system (Bailey et al., 2004).

Although similarities point to restoration success, differences were also apparent. For example, in terms of functional group similarity, the PLC was significantly different from reference sites. The PLC has greater cover of annual grasses and lacked many of the forbs found on the Pawnee sites. Since no forbs were included in the re-vegetation effort, this could explain the lower number of forbs present on the site. In addition, the PLC had significantly lower levels of phosphorus, potassium and estimated nitrogen release. Because of some of the different species at the PLC and different soil conditions, the established vegetation following reclamation will be slightly different than reference sites as in expected in any restoration site (Choi, 2004). But, the high percentage of ground cover and established native perennials indicate continued sustainability of this site as seen for other degraded sites in arid regions (Aronson et al., 1993).

Recommendations for continued progression of the reclamation process include planting more native forbs, which should increase species diversity, and continued weed control. Increasing nitrogen and phosphorus levels should bring the soil closer to reference site conditions but should be used with caution because of the possible increase in noxious annual grasses through this treatment (Cherwin et al., 2009). While the above study suggests restoration success, many land stewards lack an understanding of mechanistic controls which could be used to alter restoration procedures for increased efficacy.

Mechanistic Community Response to Disturbance

Greenhouse and field studies were used to assess the importance of competition and grazing on shortgrass steppe communities. These studies were focused on riparian zones that have lacked adequate study and noxious weeds that decrease the effectiveness of restoration efforts (Sheley & Krueger-Mangold, 2003). Precipitation levels, flood tolerance, ability to tolerate soil nutrient levels, grazing tolerance and propagule pressure/availability all appeared to be major drivers of shortgrass steppe vegetation and determine vegetation response to disturbance. Riparian areas of the shortgrass steppe appeared resilient to release from cattle grazing. Overall community composition and structure, diversity, species-specific responses, and soil characteristics showed few significant differences between moderately-grazed and un-grazed plots. In terms of structure, an increase in litter was observed every year in the exclosure. This build-up of litter over time could impact which species germinate and will likely change soil composition (Xiong & Nilsson, 1999), but such changes were not evidenced in the release from grazing study. Further, grazing had a minimal impact on horizontal vegetation structure but a significant impact on vertical vegetation structure. Over one grazing season, patchiness increased in plots that were grazed with more bare ground present in the grazed plots.

Composition started out different for the exclosures compared to grazed areas. Within the five year period of time, change in vegetation composition occurred both in areas released from grazing and in areas exposed to continuous grazing, although more compositional change occurred in areas excluded from grazing. Mild grazing effects were indicated with perennial grasses being better adapted to grazing than forbs (Amiri et al., 2008). In the absence of grazing, forbs generally become more prominent (Hazlett 1992).

Contrary to expectations, grazing had no significant impact on species richness or diversity in either release-from-grazing study. Richness and diversity measurements followed the same general patterns for both exclosure and grazed transects. The general trend was a decrease initially followed by an increase. The diversity increased sooner in grazed areas (Simpson's index) than exclosures. Diversity remained less in grazed transects throughout the study which is expected as grazing is predicted to decrease diversity in dry environments (Olff & Ritchiee, 1998). Richness of species decreased for the first four years but increased substantially in the last year of the study. Richness increased more in the released transects than grazed transects, but contributed to a decrease in species evenness.

Because of the similar patterns seen with grazing for evenness, richness, species diversity, change in species composition, and change in functional composition, some variable other than grazing is likely driving vegetation dynamics. Such drivers could include historical effects (Quetier et al., 2007), propagule pressure (Davis et al., 2000), community resiliency (Briske et al., 2006), and climate change (Lauenroth & Sala, 1992).

The Pawnee National Grasslands have been under the influence of widespread grazing for years (Larson, 1940). Because of this historical effect, potential riparian species susceptible to grazing have likely been removed from the system. The isolation of site locations from riparian areas unaffected by grazing likely resulted in a lack of propagule pressure. After only five years, it is unlikely many new seeds had been brought into the system. A longer period of time may allow for dispersal of some of these species into areas protected from grazing and enable a better conclusion to be drawn on the impact of grazing (Levin et al., 2003). Conversely, studying a complimentary riparian site not exposed to grazing may give a better indication of the impact of grazing in these areas.

Another component of propagule pressure is noxious weeds. Impacts on the PLC were likely greater because of increased propagule pressure and available space created through the mining process. Species present at the PLC have the ability to produce many seeds and have excellent dispersal characteristics. However, such noxious species must have the adaptive means to withstand the water limiting environment of the shortgrass steppe and the ability to invade shortgrass communities. Competition studies indicated that as space becomes less available through the growth of native vegetation, the impact of noxious weeds will likely decrease (Sheley & Carpinelli, 2005). In other words, shortgrass steppe communities have some resiliency to exotic species invasion.

An increase in competition was noted for *Achillea*, *Cirsium* and *Vulpia* as plant density levels increased from 2 to 4 and 6 plants per pot. For *Bromus*, the native species *Vulpia* inhibited growth and suggests a biological control for the exotic (Dukes, 2000). This decrease was noted for three different variables including number of leaves, aboveground biomass, and belowground biomass. *Vulpia* similarly showed a decrease in growth when grown with *Bromus*. Intraspecific competition was also demonstrated in both *Bromus* and *Vulpia*. The combination of intraspecific and interspecific competition may explain the coexistence of these species in the field as hypothesized by Tilman & Pacala (1993).

In the field, *Cirsium* showed a positive correlation when grown with other forbs and a negative correlation when grown with clonal grasses. Decreased growth was determined for above ground biomass, height and number of flower structures. The decrease in number of flowers as grass percentage increased showed a direct decrease in fecundity and may suggest stronger competition with perennial grasses than forbs: perennial grasses may be more functionally equivalent to the clonal *Cirsium* than other forbs. Further, the greatest cover of forbs in the study was actually additional *Cirsium*, so intraspecific competition may be notably less than interspecific and partially explain the invasiveness of *Cirsium* (Bossdorf et al., 2004).

Overall, more research should be conducted to determine other native species' competitive potential against noxious weeds on the shortgrass steppe. Perhaps native forbs other than *Achillea* would inhibit the growth of *Cirsium*. Revegetation in general should be encouraged in disturbed areas and areas infested with noxious weeds, as vegetation cover was shown to decrease the prevalence of *Cirsium*. In particular, continued planting of perennial grasses is a good strategy on the short grass steppe for mitigating the invasion of *Cirsium arvense*. Results indicate *Vuplia* could be used to lessen the impact of *Bromus*. Experimenting with seeding this species in areas invaded with *Bromus* to determine its effectiveness in the field is recommended.

The PLC being impacted both by flooding and gravel mining has plants on site (some planted) that respond well to residual site conditions of both of these assaults. In addition, the PLC soil is alkaline. *Sporobolus airoides* and *Distichlis stricta* are alkali-tolerant species that appear to be flood tolerant; for these reasons, these species were prevalent at the PLC. These plants are also common at Pawnee site 17 indicating similar factors shaping this community. As the PLC continues to move through the process of succession, such factors will continue to shape which plants become dominant in the community. Although restoration appears to have some efficacy, and that efficacy can be explained by mechanistic processes, restoration efforts will be limited without public support and understanding.

The Necessity for Experiential Environmental Education

Developing public support and understanding begins with education and the qualitative study conducted was aimed at evaluating how students were impacted by visiting a gravel mine reclamation site to determine if this activity would heighten students awareness of and need for reclamation. Students benefitted from the site visit by gaining a more complete picture of the process of reclamation. Some misperceptions still persisted and many students did not go into much detail concerning the benefits and purpose of reclamation, but students were able to gain a sense of place from this experience and that increased their perceptions about the process. Students also shifted away from a human-centered purpose for mine reclamation and included more broadly the plant and animals of the natural world.

As human impact on the environment continues to increase, understanding how students think about these modified environments becomes critical in connecting with students and helping them develop responsible stewardship toward the environment (NAAEE, 2004). This study showed that being explicit in teaching reclamation, giving students specific experiences at reclamation sites, and relating directly to these sites when discussing the process of reclamation improved student understanding and attitudes toward reclamation. To develop a sense of eco-consciousness, it is necessary to talk about the importance of reclamation. By encouraging students to think about what would happen if mine reclamation did not occur, students were able to gain a perspective on the importance of the process. The experience of visiting the mine site appeared to solidify the connection to the topic. Connection of the topic for students can be further enhanced by having them identify themes related to reclamation. These themes may be anthropocentric, such as the importance mineral resources have for our society, may increase recreational activities and locales, or may connect to the idea of the damage un-reclaimed sites confer to the environment.

This study indicated the importance of place-based education in enabling students to make appropriate connections about mine reclamation. Development of other activities could be incorporated at the mine site which would broaden the understanding of the process and connect the students to specific plants being selected at the site for reclamation. Including these plants in the mining simulation could further enhance appreciation and care for nature.

Conclusion

In conclusion, these studies investigating disturbance ecology and restoration increase our knowledge of how the shortgrass steppe responds to disturbance. These results will contribute to the management of natural areas in the region degraded by human impact. For example, invasive species clearly compete with natives but native shortgrass steppe communities dominated by perennial grasses offer some resilience to invasion, and environmental controls such as climate and soil nutrient levels provide strong filters of community assembly. Additionally, the qualitative study contributed to a greater understanding of the impact visiting a reclamation site had on students and can be used to facilitate a successful transition toward eco-consciousness in students. Collectively, the information can be used to minimize anthropogenic impact and ensure individual connection with the environment so that future generations have the ability to enjoy a quality of life that is equal to that of the current generation.

REFERENCES

Aarssen, L. W. 1989. Competitive ability and species coexistence: a 'plant's-eye' view. Oikos **56:**386-401.

Adler, P. B., D. G. Milchunas, W. K. Lauenroth, and I. C. Burke 2004. Functional traits of graminoids in semi-arid steppes: a test of grazing histories. Journal of Applied Ecology **41:**653–663.

Anderson, R. C. 2006. Evolution and origin of the Central Grassland of North America: climate, fire, and mammalian grazers. Journal of the Torrey Botanical Society **133:**626-647.

Anderson, V. J., and D. D. Briske 1995. Herbivore-induced species replacement in grasslands: is it driven herbivory tollerance or avoidance? Ecological Applications **5:**1014-1024.

Ang, B. N., L. T. Kok, G. I. Holtzman, and D. D. Wolf 1995. Canada thistle (*Cirsium arvense*) response to density of *Cassida rubiginosa* (Coleoptera: Chrysomelidae) and plant competition. Biological Control **5:**31-38

Aphalo, P. J., C. L. Ballaré, and A. L. Scopel 1999. Plant-plant signalling, the shade-avoidance response and competition. Journal of Experimental Botany **50:**1629-1634.

Amiri, F., A. Ariapour, and S. Fadai 2008 Effects of livestock grazing on vegetation composition and soil moisture properties in grazed and non-grazed range site. Journal of Biological Sciences **8:**1289-1297.

Aronson, J., C. Fled, E. Le Floc'hl, C. Ode, and R. R Pontanier 1993. Restoration and Rehabilitation of Degraded Ecosystems in Arid and Semi-Arid Lands. Restoration Ecology **1:**8-17.

Ashby M. CPER Site Manager for the Ag Research Service 2010. Personal communication.

Assembly, C. G. 2008. Colorado Land Reclamation Act for the Extraction of Construction Materials.

Bailey, R. C., R. H. Norris, and T. B. Reynoldson. 2004. Bioassessment of freshwater ecosystems using the reference condition approach. Kluwer Academic Publishers, Norwell, MA.

Baker, W. B. 1989. Classification of the riparian vegetation of the montane and subalpine zones in western Colorado. Western North American Naturalist **49:**214-228.

Banning, N. C., C. D. Grant, D. L. Jones, and D. V. Murphy 2008. Recovery of soil organic matter, organic matter turnover and nitrogen cycling in a post-mining forest rehabilitation chronosequence. Soil Biology & Biochemistry **40:**2021-2031.

Beck, K. G. 2008. Canada thistle. Colorado State University Extension, Ft. Collins.

Bengtsson, J., T. Fagerstrom, and H. Rydin 1994. Competition and coexistence in plant communities. Trends in Ecology & Evolution **9:**246-250.

Bezemer, T. M., O. Graca, P. Rousseau, and W. H. Van Der Putten 2004. Above and belowground trophic interactions on creeping thistle (*Cirsium arvense*) in high and low diversity plant communities: potential for biotic resistance? Plant Biology **6:**231-238.

Bisevac, L., and J. D. Majer 1999. Comparative study of ant communities of rehabilitated mineral sand mines and heathland, western Australia. Restoration Ecology **7:**117-126.

Blank, R. R. 2010. Inraspecific and interspecific pair-wise seedling competition between exotic annual grasses and native perennials: plant - soil relationships. Plant Soil **326:**331-343.

Blensky, J. A., and D. M. Blumenthal 1997. Effects of livestock grazing on stand dynamics and soils in upland forests of the interior west. Conservation Biology **11:**315-327.

Bloodworth, A. J., P. W. Scott, and M. F. M. 2009. Digging the backyard: Mining and quarrying in the UK and their impact on future land use. Land Use Policy **26:**317-325.

Bonham, C. D. 1989. Measurements for terrestrial vegetation. John Wiley & Sons, New York.

Bossdorf, O., D. Prati, H. Auge, and B. Schmid 2004. Reduced competitive ability in an invasive plant. Ecology Letters **7:**346-353.

Bradshaw, A. 1997. Restoration of mined lands - using natural processes. Ecological Engineering **8:**255-269.

Bradshaw, A. 2000. The use of natural processes in reclamation - advantages and difficulties. Landscape and Urban Planning **51:**89-100.

Bradshaw, A. 2002. Introduction and philosophy. Pages 3-9 in M. R. Perrow and A. J. Davy, editors. Handbook on ecological restoration: Volume 1. Principals of restoration. Cambridge University Press, Cambridge, United Kingdom.

Bradshaw, A. D., R. W. Lodge, J. D., and C. M. J. 1960. Experimental investigations into the mineral nutrition of several grass species: part II. pH and calcium level. Journal of Ecology **48:**143-150.

Briske, D. D., S. D. Fuhlendorf, and F. E. Smeins 2006. A unified framework for assessment and application of ecological thresholds. Rangeland Ecology & Management **59:**225-236.

Brown, J. C. 1978. Mechanism of iron uptake by plants. Plant, Cell & Environment **1:**249-257.

Burke, I. C., W. K. Lauenroth, R. Riggle, P. Brannen, B. Madigan, and S. Beard 1999. Spacial variability of soil properties in the shortgrass steppe: the relative importance of topography, grazing, microsite, and plant species in controlling spacial patterns. Ecosystems **2:**422-438.

Burke, M. J. W., and J. P. Grime 1996. An experimental study of plant community invasibility. Ecology **77:**776-790.

Cakir, M. 2008. Constructivist approaches to learning in science and their implications for science pedagogy: a literature review. Internarnational Journal of Environmental & Science Education **3:**193-206.

Callaway, R. M., and E. T. Aschehoug 2000. Invasive plants versus their new and old neighbors: a mechanism for exotic invasion. Science **290:**521-523.

Callaway, R. M., and L. R. Walker 1997. Competition and facilitation: a synthetic approach to interactions in plant communities. Ecology **78:**1958-1965.

Carlson, A. M., and D. L. Gorchov 2004. Effects of herbicide on the invasive biennial *Alliaria petiolata* (Garlic Mustard) and initial responses of native plants in a southwestern Ohio forest. Restoration Ecology **12:**559-567.

Carpinalli, M. F., R. L. Sheley, and B. D. Maxwell 2004. Revegetating weedinfested rangeland with niche-differentiated desirable species. Journal of Range Management **57:**97-105.

Casper, B. B., and R. B. Jackson 1997. Plant competition underground. Annual Review of Ecology, Evolution, and Systematics **28:**545-570.

Chambers, J. C., B. A. Roundy, R. R. Blank, S. Meyer, and W. A 2007. What makes great basin sagebrush ecosystems invasible by *Bromus tectorum*? Ecological Monographs **77:**117–145.

Chapman, R., and A. Younger 1995. The establishment and maintenance of a species-rich grassland on a reclaimed opencast coal site. Restoration Ecology **3:**39-50.

Cherwin, K. L., T. R. Seastedt, and K. N. Suding 2009. Effects of nutrients manipulations and grass removal on cover species composition, and invasibility of a novel grassland in Colorado Restoration Ecology **17:**818-826.

Choi, Y. D. I. 2004. Theories for ecological restoration in changing environment: Toward 'futuristic' restoration. Ecological Research **19**:75–81.

Choi, Y. D. 2007. Restoration ecology to the future: a call for new paradigm. Restoration Ecology **15:**351-353.

Christiansen, S., and T. Svejcar 1988. Grazing effects on shoot and root dynamics and above- and below-ground non-structural carbohydrate in Caucasian bluestem. Grass and Forage Science **43:**111-119.

Cingolani, A. M., I. Noy-Meir, and S. Diaz 2005. Grazing effects on rangeland diversity: a synthesis of contemporary models. Ecological Applications **15:**757-773.

Clary, W. P., and B. F. Webster 1989. Managing grazing of riparian areas in intermountain region. Pages 1-11. USDA Forest Service.

Coffin, D. P., W. A. Laycock, and W. K. Lauenroth 1998. Disturbance intensity and above- and belowground herbivory effects on long-term (14 y) recovery of a semiarid grassland. Plant Ecology **139:**221-233.

Collins, S. L., and S. C. Barber 1985. Effects of disturbance on diversity in mixed-grass prairie. Plant Ecology **64:**87-94.

Corbett, E. A., R. C. Anderson, and C. S. Rogers 1996. Prairie revegetation of a stripmine in Illinois: fifteen years after establishment. Restoration Ecology **4:**346-354.

Crabb, J. A. 1982. Soil survey of Weld County, Colorado northern part Pages 157 in United States Department of Agriculture Soil Conservation Service with Colorado Agricultural Experiment Station. Station, editor.

Crotty, M. 1998. The Foundations of social research. Sage Publications London, UK.

Cullen, W. R., and C. P. Wheater 1993. The flora and invertebrate fauna of a relocated grassland at Thrislington Plantation, County Durham, England. Restoration Ecology **1:**130-137.

Daehler, C. C. 2003. Performance comparisons of co-occurring native and alien invasive plants: Implications for conservation and restoration. Annual Review of Ecology, Evolution, and Systematics **34:**183-211

Darwin, C. 1859. The origin of species. J. Murray, London.

Davies, K. F., S. Harrison, H. D. Safford, and J. H. Viers 2007. Productivity alter the scale dependence of the diversity- invasibility relationship. Ecology **88:**1940-1947.

Davis, J. 1998. Young children, environmental education, and the future Early Childhood Education Journal **26:**117-123.

Dennis, J. 1992. It's raining frogs and fishes - four seasons of natural phenomena and oddities of the sky. HarperCollins Publishers Inc, New York NY.

Denslow, J. S. 1980. Patterns of plant species diversity during succession under different disturbance regimes. Oecologia **46:**18-21.

Derner, J. D., and R. H. Hart 2007. Livestock and vegetation responses to rotational grazing in short-grass steppe. Western North American Naturalist **67:**359-367.

Derner, J. D., and A. J. Whitman 2009. Plant interspaces resulting from contrasting grazing management in northern mixed-grass prairie: implications for ecosystem function. Rangeland Ecology & Management **62:**83-88.

Dewey, J. 1938. Experience and education. The Macmillan Company, New York.

Diaz, S., and M. Cabido 2001. Vive la difference: plant functional diversity matters to ecosystem processes. Trends in Ecology and Evolution **16:**646-655.

Diez, J. M., J. J. Sullivan, P. E. Hulme, G. Edwards, and R. P. Duncan 2008. Darwin's naturalization conundrum: dissecting taxonomic patterns of species invasions. Ecology Letters **11:**674–681.

Ditommaso, J. M. 2000. Invasive weeds in rangelands: species, impacts, and management. Weed Science **48:**255-265.

Ditommaso, J. M., and D. W. Johnson 2006. The use of fire as a tool for controlling invasive plants Pages 56. Cal-IPC Publication 2006-01. California Invasive Plant Council, Berkeley, CA.

Dodd, M. B., and W. K. Lauenroth 1997. The influence of soil texture on the soil water dynamics and vegetation structure of a shortgrass steppe ecosystem. Plant Ecology **133:**13-28.

Donahue, R. L., R. W. Miller, and J. C. Shickluna. 1977. Soils and introduction to soils and plant growth 4th ed. Prentice-Hall, Englewood Cliffs.

Dove, J., L. Everett, and P. Preece 1997. The urban child's concentration of a river. Landscape Research **22:**52-56.

Drew, L. J., W. H. Langer, and J. S. Sachs 2002. Environmentalism and natural aggregate mining. Natural Resources Research **11:**19-28.

Dukes, J. 2000. Biodiversity and invasibility in grassland microcosms. Oecologia **126:**563-568.

Ehrendorfer, F. 1973. New chromosome numbers and remarks on theAchillea millefolium polyploid complex in North America. Plant Systematics and Evolution **122** 133-143.

Eliason, S. A., and E. B. Allen 1997. Exotic grass competition in suppressing native shrubland re-establishment. Restoration Ecology **5:**245-255.

Elton, C. S. 1958. The ecology of invasions by animals and plants. Methuen, London.

Emery, S. M. 2007. Limiting similarity between invaders and dominant species in herbaceous plant communities? Journal or Ecology **95:**1027-1035.

Epstein, H. E., I. C. Burke, and W. K. Lauenroth 1999. Response of the shortgrass steppe to changes in rainfall seasonality. Ecosystems **2:**139-150.

Eschtruth, A. K., and J. J. Battles 2009. Assessing the relative importance of disturbance, herbivory, diversity, and propagule pressure in exotic plant invasion Ecological Monographs **79:**265-280.

Fairchild, J. F., D. S. Ruessler, P. S. Haverland, and A. R. Carlson 1997. Comparative sensitivity of *Selenastrum capricornutum* and Lemna minor to sixteen herbicides. Environmental Contamination and Toxicology **32:**353-357.

Felixa, J., D. J. Doohana, and D. Bruins 2007. Differential vegetable crop responses to mesotrione soil residues a year after application. Crop protection **26** 1395–1403.

Frouz, J., K. Prach, V. Pizl, L. Hanel, J. Stary, K. Tajovsky, J. Materna, V. Balik, J. Kalcik, K. Rehounkova 2008. Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. European Journal of Soil Biology **44:**109-121.

Fuhlendorf, S. D., and D. M. Engle 2001. Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns. BioScience **51:**625-632.

Fuhlendorf, S. D., H. Zhang, T. R. Tunnell, D. M. Engle, and A. F. Cross 2002. Effects of grazing on restoration of southern mixed prairie soils. Restoration Ecology **10:**401-407.

Fujita, N., N. Amartuvshin, Y. Yamada, K. Matsui, S. Sakai, and N. Yamamura 2009. Positive and negative effects of livestock grazing on plant diversity of Mongolian nomadic pasturelands along a slope with soil moisture gradient. Grassland Science **55:**126–134.

Garnier, E. 1992. Growth analysis of congeneric annual and perennial grass species. Journal of Ecology **80:**665-675.

Gause, G. F. 1934. The struggle for existance. Williams and Wilkins, Baltimore, MA.

Gibson, D. J., B. A. Middleton, G. W. Saunders, M. Mathis, W. T. Weaver, J. Neely, J. Rivera, and M. Oyler 1999. Learning ecology by doing ecology: long-term field experiments in succession. The American Biology Teacher **61:**217-222.

Gitay, H., and I. R. Noble 1997. What are functional types and how should we seek them? Pages 3-19 in T. M. Smith, H. H. Shugart and F. I. Woodward, editors. Plant Functional Types. Cambrige University Press, New York, NY.

Giuliano, W. M., and J. D. Homyack 2004. Short-term grazing exclusion effects on riparian small mammal communities. Journa of Range Management **57:**346-350.

Goldberg, D. E., and A. M. Barton 1992. Patterns and consequences of interspecific competition in natural communities: A review of field experiments with plants. The American Naturalist **139:**771-801.

Gray, A. 1879. The predominance and pertinacity of weeds. Journal of Science and Arts **118:**161-167.

Grime, J. P. 1977. Evidence for the existence of three primary strategies in plants and its relavance to ecological and evolutionary theory. The American Naturalist **111:**1169-1194.

Grime, J. P. 2001. Plant strategies, vegetation processes, and ecosystem properties. John Wiley & Sons New York, NY

Haggar, R. J., A. K. Oswald, and W. G. Richardson 1986. A review of the impact and control of creeping thistle (*Cirsium arvense* L.) in grassland. Crop Protection **5:**73-76.

Hardin, G. 1960. The competitive exclusion principle. Science **131:**1292-1297.

Harper, J., and D. Gajic 1961. Experimental studies of the mortality and plasticity of a weed. Weed Research **1:**91–104

Hart, R. H. 2001. Plant biodiversity on shortgrass steppe after 55 years of zero, light, or heavy cattle grazzing. Plant Ecology **155:**111-118.

Hart, R. H., and M. M. Ashby 1998. Grazing intensities, vegetation and heifer gains: 55 years on shortgrass. Journal of Range Management **51:**392-398.

Hayden, A. 1934. Distribution and reproduction of Canada thistle in Iowa. American Journal of Botany **21:**355-373.

Hazlett 1998. Vascular Plant Species of the Pawnee National Grassland. Pages 1-32. USDA, Forest Service, Rocky Mountain Research Station.

Hazlett, D. H. 1992 Leaf area development of four plant communities on the Colorado steppe. American Midland Naturalist **127:**276-289.

Hierro, J. L., J. L. Maron, and R.M. Callaway 2005. A biogeographical approach to plant invasions: the importance of studying exotics in their introduced and native range. Journal of Ecology **93:**5-15.

Hinsinger, P. 2001. Bioavailablility of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. Plant and Soil **237:**173-195.

Hoar, S. K., A. Blair, F. F. Holmes, C. D. Boysen, R. J. Robel, R. Hoover, and J. F. Fraumeni 1986. Agricultural herbicide use and risk of lymphoma and soft-tissue sarcoma. JAMA **256:**1141-1147.

Hobbs, R. J., and A. M. Harold 1991. Effects of rainfall variability and gopher disturbance on serpentine annual grassland dynamics. Ecology **72:**59–68.

Hobbs, R. J., and L. F. Huenneke 1992. Disturbance, diversity, and Invasion: Iplication for conservation. Conservation Biology **6:**324-337

Hodgson, J. M. 1968. The nature, ecology, and control of Canada thistle. U.S. Department of Agriculture Technical Bulletin

Holzsapfel, C., P. Shahrokh, and D. Kafkewitz 2010. Polyphenol oxidase avctivity in the roots of seedlings of *Bromus* (Poaceae) and other grass genera American Journal of Botany **97:**1195-1199.

Hooper, D. U., and J. S. Dukes 2010. Functional composition controls invasion success in a California serpentine grassland. Journal of Ecology **98:**764-777.

Hoorman, J. J., and J. Mccutcheon 2005. Best management practices to control the effects of livestock grazing on riparian areas. Pages 1-6 in L. Owens, S. Loerch and R. Hendershott, editors. Ohio State University Extension Fact Sheet Ohio State University Extension, Columbus, Ohio.

Houston, W. R., and D. N. Hyden 1976. Controlling sixweek fescue on shortgrass range. Journal of Range Management **29:**151-153.

Hulbert, L. C. 1955. Ecological studies of *Bromus tectorum* and other annual bromegrasses. Ecological Monographs **25:**181-213.

Indorante, S. J., I. J. Jansen, and C. W. Boast 1981. Surface mining and reclamation: initial changes in soil character Journal of Soil and Water Conservation **36:**347-351.

Ives, A. R. 1995. Measuring resilience in sochastic systems. Ecological Monographs **65:**217-233.

Jick, T. D. 1979. Mixing qualitative and quantitative methods: triangulation in action. Administrative Science Quarterly **24:**602-611.

Kauffmann, B. J., and W. C. Krueger 1984. Livestock impacts on riparian ecosystems and streamside management implications a review. Journal of Range Management **37:**430-438.

Kirmer, A., S. Tischew, W. A. Ozinga, M. Von Lampe, A. Baasch, and J. M. Van Groenendael 2008. Importance of regional species pools and functional traits in colonization processes: predicting re-colonization after large-scale destruction of ecosystems. Journal of Applied Ecology **45:**1523-1530.

Knapp, C. E. 1999. In accord with nature: helping students form an environmental ethic using outdoor experience and reflection. ERIC/CRESS, Appalachia Educational Laboratory, Chareston, WV.

Kolar, C. S., and D. M. Lodge 2001. Progress in invasive biology: predicting invaders. Trends in Ecology & Evolution **16:**199-204.

Kotanen, P. M., J. Bergelson, and D. L. Hazlett 1998. Habitats of native and exotic plants in Colorado shortgrass steppe: a comparative approach. Canadian Journal of Botany **76:**664-672.

Kreyling, J., L. E. Beierkuhnlein, and A. Jentsch 2008. Invasibility of grassland and heath communities exposed to extreme weather events - additive effects of diversity resistance and fluctuating physical environment. Oikos **117:**1542-1554.

Langer, W. H., and B. F. Arbogast 2002. Environmental impacts of mining natural aggregate Pages 151-169 in A. G. Fabbri, G. Gaal and R. B. Mccammon, editors. Deposit and Geoenvironmental Models for Resource Exploitation and Environmental Security. Kluwer Academic Publishers, Boston.

Larson, D. L. 2003. Native weeds and exotic plants: relationships to disturbance in mixed-grass prairie. Plant Ecology **169:**317–333.

Larson, F. 1940. The role of bison in maintaining the shortgrass plains. Ecology **21:**113-121.

Lauenroth, W. K. 2008. Vegetation of the shortgrass steppe. Pages 70-83 in W. H. Langer and I. C. Burke, editors. Ecology of the shortgrass steppe a long-term perspective Oxford University Press, New York.

Lauenroth, W. K., I. C. Burke, and J. A. Morgan 2008. The shortgrass steppe the region and research sites Pages 3-13 in W. K. Lauenroth and I. C. Burke, editors. Ecology of the shortgrass steppe. Oxford University Press, New York.

Lauenroth, W. K., and D. G. Milchunas 1991a. The shortgrass steppe. Pages 183-226 in Coupland, editor. Ecosystems of the World. Elsevier, New York.

Lauenroth, W. K., and D. G. Milchunas 1991b. The shortgrasse steppe. Pages 183-226 in R. T. Coupland, editor. Ecosystems of the World. Elsevier, New York.

Lauenroth, W. K., and O. E. Sala 1992. Long-term forage production of North American shortgrass steppe Ecological Applications **2:**397-403.

Lavorel, S., S. Mcintyre, J. Landsberg, and T. D. A. Forbes 1997. Plant functional classifications: from general groups to specific groups based on response to disturbance. Trends in Ecology & Evolution **12:**474-478.

LeCain, D. R., J. A. Morgan, G. E. Schumann, D. Reeder Jean, and R. H. Hart 2002. Carbon exchange and species composition of grazed pastures and exclosures in the shortgrass steppe of Colorado. Agriculture Ecosystem & Environment **93:**421-435.

Lee, C. E. 2002. Evolutionary genetics of invasive species. TRENDS in Ecology & Evolution Vol.17 No.8 August 2002 **17:**386-391.

Levin, S. A., H. C. Muller-Landau, R. Nathan, and J. Chave 2003. The ecology and evolution of seed dispersal: a theoretical perspective. Annu. Rev. Ecol. Syst. **34:**575-604.

Leopold, A. 1949. A Sand County almanac and sketches here and there Oxford University Press, New York, NY.

Lonsdale, W. M. 1999. Global patterns of plant invasions and the concept of invasibility. Ecology **80:**1522-1536.

Louv, R. 2005. Last child in the woods. Algonquin, Chapel Hill, North Carolina.

Lucas, R. W., T. T. Baker, K. M. Wood, C. D. Allison, and D. M. Vanleeuwn 2004. Riparian vegetation response to different intensities and seasons of grazing. Journal of Range Management **57:**466-474.

Macarthur, R. H. 1972. Geographical ecology : patterns in the distribution of species. Harper & Row, New York.

Mack, R. N. 1981. Invasion of *Bromus tectorum* L. into western North America: an ecological chronicle. Agr-Ecosystems **7:**145-165.

Mack, R. N., and D. A. Pyke 1983. The domography of Bromus Tectorum variation in time and space. Journal of Ecology **71:**69-93.

Mack, R. N., and J. N. Thompson 1982. Evolution in steppe with few large, hooved mammals. The American Naturalist **119:**757-773.

Mangold, J. M., C. L. Poulsen, and M. F. Carpinelli 2007. Revegetating Russian knapweed (Acroptilon repens) infestations using morphologically diverse species and seedbed preparation. Rangeland Ecology & Management **60:**378-385.

Maron, M., and M. Marbler 2007. Native plant diversity resists invasion at both low and high resource levels. Ecology **88:**2651-2661.

Martin, L. M., K. A. Moloney, and B. J. Wilsey 2005. An assessment of grassland restoration success using species diversity components. Journal of Applied Ecology **42:**327-336.

Martin, L. M., and B. J. Wilsey 2006. Assessing grassland restoration success: relative roles of seed additions and native ungulate activities. Jornal of Applied Ecology **43:**1098-1109.

Marvier, M., P. Peter Kareiva, and M. G. Neubert 2004. Habitat destruction, fragmentation, and disturbance promote invasion by habitat generalists in a multispecies metapopulation. Risk Analysis **24:**869–878.

Mccune, B., and M. J. Metford 2006. PC-ORD. Multivariate analysis of ecological data. version 5. MjM Software, Gleneden Beach, Oregon, U.S.A.

Mcevoy, P. B., and E. M. Coombs 1999. Biological control of plant invaders: regional patterns, field experiments, and structured population models Ecological Applications **9:**387-401.

Mcnaughton, S. J. 1993. Grasses and grazers, science and management. Ecological Applications **3:**17-20.

Merriam, S. B. 1998. Qualitative Research and case study applications in education. John Wiley & Sons, San Francisco, CA.

Milchunas, D. G., J. R. Forwood, and W. K. Lauenroth 1994. Productivity of long-term grazing treatment response to seasonal precipitation. Journal of Range Management **47:**133-139.

Milchunas, D. G., and W. K. Lauenroth 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs **63:**327-366.

Milchunas, D. G., W. K. Lauenroth, and I. C. Burke 1988a. Livestock grazing: animal and plant biodiversity of shortgrass steppe and the relationship to ecosystem function. Oikos **83:**65-74.

Milchunas, D. G., W. K. Lauenroth, and P. L. Chapman 1992. Plant competition, abiotic, and long- and short-term effects of large herbivores on demography of opportunistic species in a semiarid grassland. Oecologia **92:**520-531.

Milchunas, D. G., O. E. Sala, and W. K. Lauenroth 1988b. A generalized model of the effects of grazing by large herbivores on grassland community. The American Naturalist **132:**87-106.

Milchunas, G. D., and W. K. Lauenroth 1989. Three-dimensional distribution of plant biomass in relation to grazing and topography in the shortgrass steppe. Oikos **55:**82-86.

Moore, R. J. 1975. The biology of Canadian weeds: *Cirsium arvense* (L.) Scop. Canadian Journal of Plant Science **55:**1033-1048.

Mueller, M. P. 2011. Lessons from the tree that owns itself: implications for education. Internarnational Journal of Environmental & Science Education **6:**293-314.

Munson, S. M., and W. K. Lauenroth 2011. Plant community recovery following restoration in semiarid grasslands. Restoration Ecology. DOI: 10.1111/j.1526-100x.2011.00808.x

NAAEE 2004. Excellence in environmental education: guidelines for learning (K-12) 2nd Edition, Rock Spring, GA

Ng, J. C. 2002. Degradation of land and its relation to public health Pages 7-18 in M. H. Wong and B. A. D., editors. The Restoration and Management of Derelict Land. World Scientific Publishing Co. Pte. Ltd. , River Edge.

Olff, H., and M. Ritchiee 1998. Effects of herbivores on grassland plant diversity. Trends in Ecology and Evolution **13:**261-265.

Orsi, L., L. Delabre, A. Monnereau, P. Delval, C. Berthou, P. Fenaux, G. Marit, P. Soubeyran, F. Huguet, N. Milpied, M. Leporrier, D. Hemon, Troussard, and J. Clavel 2009. Occupational exposure to pesticides and lymphoid neoplasms among men: results of a French case-control study. Occup Environ Med **66:**291-298.

Owensby, C. E. 1969. Effect of cages on herbage yield in true prairie vegetation. Journal of Range Management **22:**131-132.

Palmblad, I. G. 1968. Experimantal populations of weeds with emphasis on the regulation of population size. Ecology **49:**26-34.

Paruelo, J. M., and W. K. Lauenroth 1996. Relative abundance of plant functional types in grasslands and shrublands of North America **4:**1212-1224

Peters, D. P. C., W. K. Laurenroth, and I. C. Burke 2008. Ecology of the shortgrass steppe. Pages 84-118 in W. H. Langer and I. C. Burke, editors. Ecology of the Shortgrass Steppe. Oxford University Press, New York.

Pielke, R. A. S., and N. J. Doesken 2008. Climate of the shortgrass steppe. Pages 14-29 in W. K. Lauenroth and I. C. Burke, editors. Ecology of the shortgrass steppe a long-term perspective. Oxford University Press, New York.

Pihlainen-Bednarik, K., and T. Keinonen 2011. Six graders understanding of their own learning: A case study in environmental education course. Internarnational Journal of Environmental & Science Education **6:**59-78.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison 2000. Environmental and economic costs of nonindigenous species in the United States BioScience **50:**53-65.

Pitelka, L. F. 1977. Energy allocation in annual and perennial lupines (*Lupinus*: Leguminosae). Ecology **58:**1055-1065.

Pokorny, M. L., R. L. Sheley, C. A. Zabinski, R. E. Engel, T. J. Svejcar, and J. J. Borkowski 2005. Plant functional group diversity as a mechanism for invasion resistance. Restoration Ecology **13:**448-459.

Pollard, C. L. 1899. The genus *Achillea* in North America. Bulletin of the Torrey Botanical Club **26:**365-372.

Pywell, R. F., J. M. Bullock, D. B. Roy, L. Warman, K. J. Walker, and P. Rothery 2003. Plant traits as predictors of performance in ecological restoration. Journal of Applied Ecology **40:**65-77.

Quetier, F., A. Thebault, and S. Lavorel 2007. Plant traits in a state and transition framework as markers of ecosystem response to land-use change. Ecological Monographs **77:**33-52.

Rehounkova, K., and K. Prach 2010. Life-history traits and habitat preferences of colonizing plant species in long-term spontaneous succession in abandoned gravel-sand pits. Basic and Applied Ecology **11:**45-53.

Resh, S. C., and R. A. Chimmer. 2005. Restoration plan for the Poudre Learning Center. Poudre Learning Center, Greeley, CO.

Rice, K. J., and R. N. Mack 1991. Ecological genetics of *Bromus tectorum*. II. intraspecific variation in phenotypic plasticity. Oecologia **88:**84-90.

Ruiz-Jaen, M. C., and M. T. Aide 2005. Restoration success: How it is being measured. Restoration Ecology **13:**569-577.

Rutherford, M. C., L. W. Powrie, and L. B. Husted 2012. Plant diversity consequences of a herbivore-driven biome switch from grassland to nama-karoo shrub steppe in South Africa. Applied Vegetation Science **15:**14-25.

Schenk, J. H., and R. B. Jackson 2002. Rooting depths, lateral root spreads and below-ground/above-ground allometries of plants in water-limited ecosystems. Journal of Ecology **90:**480-493.

Schiebout, M. H., D. L. Hazlett, N. Snow, and 2008. A floristic survey of vascular plants over parts of northeastern New Mexico. Jornal of Bot. Res. Inst. of Texas **2:**1407-1448

Schimel, D., M. A. Stillwell, and R. G. Woodmansee 1985. Biochemistry of C, N, and P in a soil catena of the shortgrass steppe. Ecology **66:**276-282.

Schultz, T. T., and W. C. Leininger 1990. Differences in riparian structure between grazed areas and exclosures. Journal of Range Management **43:**295-299.

Schwartz, C. C., and J. E. Ellis 1981. Feeding ecology and niche separation in some native and domestic ungulates on the shortgrass prairie. Journal of Applied Ecology **18:**343-353.

Seabloom, E. W., E. T. Borer, V. L. Boucher, Burton, Rebecca S., K. L. Cottingham, L. Goldwasser, W. K. Gram, B. E. Kendall, and F. Micheli 2003. Competition, seed limitation, disturbance, and reestablishment of California native annual forbs **13:**575-592.

Senft, R. L., L. R. Rittenhouse, and R. G. Woodmansee 1985. Factors influencing patterns of cattle grazing behavior on shortgrass steppe. Journal of Range Management **38:**82-87.

Sengupta, M. 1993. Reclamation and revegetation of mined land. Pages 103-119 in M. Sengupta, editor. Environmental impacts of Mining Monitoring, Restoration and Control. CRC Press, Inc., Boca Raton.

SER, Society for Ecological Restoration International Science & Policy Working Group 2004. The SER International Primer on Ecological Restoration. Tucson, Arizona

Shaw, J. R., and D. J. Cooper 2008. Linkages among watersheds, stream reaches, and riparian vegetation in dryland ephemeral stream networks. Journal of Hydrology **350:**68-82.

Shaw, R. B. 2008. Grasses of Colorado. University Press of Colorado, Boulder, Colorado.

Sheley, R. L., and M. F. Carpinelli 2005. Creating weed-resistant plant communities using niche-differentiated nonnative species. Rangeland Ecology & Management **58:**480-488.

Sheley, R. L., and J. James 2010. Resistance of native plant functional groups to invasion by medusahead (*Taeniatherum caput-medusae*) Invasive Plant Science and Manegement **3:**294-300.

Sheley, R. L., and J. Krueger-Mangold 2003. Principles for restoring invasive plant-infested rangeland. Weed Science **51:**260-265.

Shepardson, D. P., B. Wee, M. Priddy, and J. Harbor 2007. Students mental mModels of the Environment. Journal of Research in Science Teaching **44:**327-348.

Singh, J. S., P. Bourgeron, and W. K. Lauenroth 1996. Plant species richness and species-area relations in a shortgrass steppe in Colorado. Journal of Vegetation Science **7:**645-650.

Skinner, M. 2008. Plant Guide: Cheat grass, *Bromus tectorum* in USDA, National Plant Data Center, Baton Rouge, Louisiana.

Smeds, P., E. Jeronen, S. Kurppa, and M.-L. Vieraankivi 2011. Rural camp school eco learn - outdoor education in rural settings. Internarnational Journal of Environmental & Science Education **6:**267-291.

Smith, R. L., and T. M. Smith. 2001. Ecology and Field Biology 6th Ed. Benjamin-Cumming Pub Co.

Snow, N. 2007. Checklist of Vascular Plants of the Southern Rocky Mountain Region (Version 2)**:**308 pp

Sousa, W. 1984. The role of disturbance in natural communities. Annu. Rev. Ecol. Syst. **15:**353-391.

Stapp, P., B. Vanhorn, and M. D. Lindquist. 2008. Ecology of mammals of the shortgrass steppe. Oxford University Press, New York.

Stockwell, C. A., A. P. Hendry, and M. T. Kinnison 2003. Contemporary evolution meets conservation biology. Trends in Ecology & Evolution **18** 94–101.

Stohlgren, T., J., K. A. Bull, Y. Otsuki, C. A. Villa, and M. Lee 1998. Riparian zones as havens for exotic plant species in the central grasslands. Plant Ecology **138:**113-125.

Stohlgren, T., J., L. D. Schell, and B. Vanden Heuvel 1999. How grazing and soil quality affect native and exotic plant diversity in Rocky Mountain grasslands. Ecological Applications **9:**45-64.

Sutherland, J. P. 1974. Multiple stable points in natural communities. The American Naturalist **108:**859-873.

Symstad, A. J. 2000. A test of the effects of functional group richness and composition on grassland invasibility. Ecology **81:**99-109.

Thacher, E., M. H. Ralphs, and T. A. Monaco 2009a. A comparison of inter- and intraspecific interference on broom snakeweed (*Gutierrezia sarothrae*) seedling growth. Invasive Plant Science and Manegement **2:**36-44.

Thacher, E., M. H. Ralphs, and T. A. Monaco 2009b. Seeding cool-season grasses to suppress broom snakeweed (*Gutierrezia sarothrae*), downy brome (*Bromus tectorum*), and weedy forbs. Invasive Plant Science and Manegement **2:**237-246.

Thomson, G., and J. Hoffman 2004. Measuring the success of environmental education programs. Canadian Parks and Wilderness Society.

Thorpe, A. S., G. C. Thelen, A. Diaconu, and R. M. Callaway 2009. Root exudate is alleopathic in invaded community but not in native community: field evidence for the novel weapons hypothesis. Journal of Ecology **97:**641-645.

Thuiller, W., L. Gallien, I. Boulangeat, F. De Bello, T. Munkemuller, C. Roquet, and S. Lavergne 2010. Resolving Darwin's naturization conundrum: a quest fro evidence. Diversity and Distributions **16:**461-475.

Tilman, D. 1986. Resources, Competition and the Dynamics of Plant Communities. Pages 51-75 in M. Crawley, editor. Plant Ecology. Blackwell Scientific Publications, Oxford.

Tilman, D. 1988. Synamics and structure of plant communities. Princeton Universty Press, Princeton, NJ.

Tilman, D. 1996. Biodiversity: population vs. ecosystem stability. Ecology **77:**350-363.

Tilman, D. 1997. Community invasibility, recruitment limitation, and grassland biodiversity Ecology **78:**81-92.

Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, and Siemann 1997. The influence of functional diversity and composition on ecosystem processes Science **277:**1300-1302.

Tilman, D., and S. Pacala 1993. The maintenance of species richness in plant communities. Pages 13-25 in R. E. Ricklefs and S. D., editors. Species Diversity in Ecological Communities. University of Chicago, Chicago.

Tschillard, R., T. Booton, R. Reinsvold, L. Rogstad, G. Philp, N. Hoban, D. Hazlett, R. Simpson, and M. Urban. 2006. Poudre Learning Center reclamation plan, Greeley, CO.

USDA Forest Service. 1988. Range plant handbook. Dover Publications, Inc., New York, NY.

USDA NRCS, 2012. URL http ://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx [accessed on 2/29/12 2012].

USDA Soil Conservation Service 1980. Soil survey of Weld County, Colorado southern part Pages 147 in USDA Soil Conservation Service with Colorado Agricultural Experiment Station. Station, editor.

Van Der Maarel, E., and A. Titlyanova 1989. Above-ground and below-ground biomass relations in steppes under different grazing conditions. Oikos **56:**364-370.

Van Eck, W. H. J. M., H. M. Van De Steeg, C. W. P. M. Blom, and H. De Kroon 2004. Is tolerance to summer flooding correlated with distribution patterns in river floodplains? A camparative study of 20 terrestrial grassland species. Oikos **107:**393-405.

Vila, M., and J. Weiner 2004. Are invasive plant species better competitors than native plant species? - evidence from pair-wise experiments. Oikos **105:**229-238.

Vitousek, P. M., C. M. D'antonio, L. L. Loope, and R. Westbrooks 1996. Biological invasions as global environmental change. American Scientist **84:**468-478.

Warwick, S. I., and L. Black 1982. The biology of canadian weeds: 52. *Achillea millefolium* L. Canadian Journal of Plant Science, **62:**163-182.

Weaver, J. E. 1968. Prairie plants and their environment. University of Nebraska Press, Lincon.

Weinig, C. 2000. Plasticity versus canalization: population differences in the timing of shade aviodance responses. Evolution **54:**441-451.

White, J., and J. L. Harper 1970. Correlated changes in plant size and number in plant populations. Journal of Ecology **58:**467-485.

White, P. S., and S. T. A. Pickett 1985. Natural disturbance and patch dynamics: an introduction. Pages 3-13 in S. T. A. Pickett and P. S. White, editors. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, Inc., San Diego.

Williamson, M., and A. Fitter 1996. The varying success of invaders. Ecology **77:**1661-1666.

Wilsey, B. J., T. B. Teaschner, P. P. Daneshgar, I. I. Forest, and W. H. Polley 2009. Biodiversity maintenance mechanisms differ between native and novel exotic-dominated communities. Ecology Letters **12:**432-442.

Wolfe, L. M. 2002. Why alien invaders succeed: Support for the escape "from" enemy hypothesis. American Naturalist **160:**705-711.

Xiong, S., and C. Nilsson 1999. The effects of plant litter on vegetation: a meta-analysis Journal of Ecology **87:**984-994.

Yow, S. H. 2008. Making Sense of human/environmental interaction: student dialogue focused on visual representations of environmental change over time. PhD Dissertation. University of Kentucky

Yurkonis, K. A., B. J. Wilsey, and K. A. Moloney 2012. Initial species pattern affects invasion resistance in experimental grassland plots. Journal of Vegetation Science **23:**4–12.

APPENDIX A

CUMULATIVE SPECIES LIST FROM PLC, PAWNEE 17, AND PAWNEE 27

Nomenclature based on the Checklist of Vascular Plants of the Southern Rocky Mountain Region (Version 2, 2007) Neil Snow	I = invasive; N = CO noxious	Habitat: P=Perennial, A=Annual; Growth Form: G=Grass, F=Forb, S=Sub Shrub; Metobolic path: C=cool season, W= warm season
Achillea millefolium L. *var. lanulosa* (Nutt.) Piper		PF
Achnatherum hymenoides (Roem. & Schult.) Barkworth		PGC
Amaranthus retroflexus L.	I	AF
Ambrosia psilostachya DC.		PF
Artemisia frigida Willd.		PS
Astragalus adsurgens Pall.		PF
Astragalus bisulcatus (Hook.) A. Gray		PF
Bouteloua dactyloides (Nutt.) J. T. Columbus		PGW
Bouteloua gracilis (Kunth) Lag.		PGW
Bromus inermis Leyss.	I	PGC
Bromus tectorum L.	I, N	AGC
Carex stenophylla Wahlenb.		PGC
Chamaesyce fendleri (Torr. & A. Gray) Small		PF
Chenopodium incanum (S. Watson) A. Heller *var. incanum*		AF
Cirsium arvense (L.) Scop.	I, N	PF
Cirsium flodmanii (Rydb.)		PF
Cleome serrulata Pursh		AF
Convolvulus arvensis L.	I, N	PF
Conyza canadensis L.	I	AF
Descurainia pinnata (Walter)		AF
Distichlis stricta (Torr.) Rydb.		PGW
Elymus elymoides (Raf.) Swezey		PGC
Elymus smithii (Rydb.) Gould		PGC
Equisetum laevigatum A. Braun		AF
Eragrostis cilianensis (All.) Vignolo ex Janch.	I	AGW
Euphorbia esula L.	I, N	PF
Glycyrrhiza lepidota Pursh		PF
Hesperostipa comata (Trin. & Rupr.) Barkworth		PGC
Heterotheca villosa (Pursh) Shinners		PF
Hordeum jubatum L.		PGC

Juncus arcticus Willd. *var. balticus* (Willd.) Trautv.		PGC
Kochia scoparia (L.) Schrad.	I	AF
Lactuca serriola L.	I	AF
Lappula occidentalis (S. Watson) Greene		AF
Lathyrus polymorphus Nutt.		PF
Lepidium densiflorum Schrad.		AF
Lithospermum incisum Lehm.		PF
Lygodesmia juncea (Pursh) D. Don ex Hook.		PF
Mirabilis linearis (Pursh) Heimerl		PF
Nassella viridula (Trin.) Barkworth		PGC
Oenothera suffretescens (Ser.) W. L. Wagner & Hoch		PF
Opuntia polyacantha Haw.		PS
Panicum capillare L.		AGW
Panicum virgatum L.		PGW
Plantago patagonica Jacq.		AF
Poa arida Vasey		PGC
Poa secunda J. Presl		PGC
Potentilla pensylvanica L.		PF
Psoralidium tenuiflorum (Pursh) Rydb.		PF
Ratibida columnifera (Nutt.) Wooton & Standl.		PF
Rosa woodsii Lindl.		PS
Rumex crispus L.	I	PF
Scorzonera laciniata L.	I	AF
Sisymbrium altissimum L.		AF
Sonchus asper (L.) Hill	I	AF
Sophora nuttalliana B. L. Turner		PF
Spartina pectinata Link		PGW
Sphaeralcea coccinea (Nutt.) Rydb.		PF
Sporobolus airoides (Torr.) Torr.		PGW
Sporobolus cryptandrus (Torr.) A.Gray		PGW
Symphyotrichum falcatum (Lindl.) G. L. Nesom		PF
Taraxacum officinale Weber ex F. H. Wigg.	I	PF
Thelesperma megapotamicum (Spreng.) Kuntze		PF
Tragopogon dubius Scop.	I	PF
Trifolium repens L.		PF
Verbena bracteata Lag. & Rodr.	I	PF
Vulpia octoflora (Walter) Rydb.		AGC

APPENDIX B

CUMULATIVE SPECIES LIST FROM PAWNEE 17, AND PAWNEE 27

Nomenclature based on the Checklist of Vascular Plants of the Southern Rocky Mountain Region (Version 2, 2007) Neil Snow	Riparian/ lowland indicator species	I = invasive N = CO noxious	Habitat: P=Perennial, A=Annual; Growth Form: G=Grass, F=Forb, S=Shrub; Metabolic path: C=cool season, W= warm season
Achillea millefolium L. *var. lanulosa* (Nutt.) Piper			PF
Ambrosia psilostachya DC.			PF
Artemisia frigida Willd.			PS
Astragalus adsurgens Pall.			PF
Astragalus bisulcatus (Hook.) A. Gray			PF
Bouteloua dactyloides (Nutt.) J. T. Columbus			PGW
Bouteloua gracilis (Kunth) Lag.			PGW
Carex stenophylla Wahlenb.			PGC
Chamaesyce fendleri (Torr. & A. Gray) Small			PF
Chenopodium incanum (S. Watson) A. Heller *var. incanum*			AF
Cirsium arvense (L.) Scop.		I, N	PF
Cirsium flodmanii (Rydb.)	*yes*		PF
Cleome serrulata Pursh	*yes*		AF
Convolvulus arvensis L.		I, N	PF
Conyza canadensis L.		I	AF
Descurainia pinnata (Walter)			AF
Distichlis stricta (Torr.) Rydb.			PGW
Elymus elymoides (Raf.) Swezey			PGC
Elymus smithii (Rydb.) Gould			PGC
Equisetum laevigatum A. Braun	*yes*		AF
Glycyrrhiza lepidota Pursh	*yes*		PF
Hesperostipa comata (Trin. & Rupr.) Barkworth			PGC
Heterotheca villosa (Pursh) Shinners			PF
Hordeum jubatum L.			PGC
Juncus arcticus Willd. *var. balticus* (Willd.) Trautv.	*yes*		PGC

Kochia scoparia (L.) Schrad.		I	AF
Lactuca serriola L.		I	AF
Lappula occidentalis (S. Watson) Greene			AF
Lathyrus polymorphus Nutt.			PF
Lepidium densiflorum Schrad.			AF
Lithospermum incisum Lehm.			PF
Lygodesmia juncea (Pursh) D. Don ex Hook.			PF
Mirabilis linearis (Pursh) Heimerl			PF
Nassella viridula (Trin.) Barkworth			PGC
Oenothera suffretescens (Ser.) W. L. Wagner & Hoch			PF
Opuntia polyacantha Haw.			PS
Plantago patagonica Jacq.			AF
Poa arida Vasey			PGC
Poa secunda J. Presl			PGC
Potentilla pensylvanica L.	*yes*		PF
Psoralidium tenuiflorum (Pursh) Rydb.			PF
Ratibida columnifera (Nutt.) Wooton & Standl.			PF
Rosa woodsii Lindl.			PS
Sisymbrium altissimum L.			AF
Sonchus asper (L.) Hill	*yes*	I	AF
Sophora nuttalliana B. L. Turner			PF
Sphaeralcea coccinea (Nutt.) Rydb.			PF
Sporobolus airoides (Torr.) Torr.			PGW
Sporobolus cryptandrus (Torr.) A.Gray			PGW
Symphyotrichum falcatum (Lindl.) G. L. Nesom			PF
Taraxacum officinale Weber ex F. H. Wigg.		I	PF
Thelesperma megapotamicum (Spreng.) Kuntze			PF
Tragopogon dubius Scop.		I	PF
Trifolium repens L.			PF
Verbena bracteata Lag. & Rodr.		I	PF
Vulpia octoflora (Walter) Rydb.			AGC

APPENDIX C

CUMULATIVE SPECIES RECORDED BY CPER CREW FROM PAWNEE 17 (1995-1999)

Nomenclature based on the Checklist of Vascular Plants of the Southern Rocky Mountain Region (Version 2, 2007) Neil Snow	Riparian	I = invasive N = CO noxious	Habitat: P=Perennial, A=Annual; Growth Form: G=Graminoid, F=Forb, S=Sub Shrub; Metobolic path: C=cool season, W= warm season
Agrostis stolonifera L.		I	PGC
Allium textile A. Nelson & J. F. Macbr			PF
Ambrosia psilostachya DC.			PF
Ambrosia tomentosa Nutt.			PF
Antennaria parvifolia Nutt.			PF
Argemone polyanthemos (Fedde) G. B. Ownbey			AF
Aristida purpurea Nutt. var. *longiseta* (Steud.) Vasey			PGW
Artemisia dracunculus L.			PF
Asclepias viridiflora Raf.			PF
Astragalus drummondii Douglas ex Hook.			PF
Astragalus gracilis Nutt.			PF
Astragalus mollissimus Torr.			PF
Astragalus pectinatus (Hook.) Douglas ex G. Don			PF
Atriplex canescens (Pursh) Nutt.			PS
Bouteloua dactyloides (Nutt.) J. T. Columbus			PF
Bouteloua gracilis (Kunth) Lag.			PGW
Bromus tectorum L.		N	AGC
Carex nebrascensis Dewey	*yes*		PGC
Carex sp			PGC
Carex stenophylla Wahlenb.			PGC
Chamaesyce glyptosperma (Engelm.) Small			AF
Chenopodium leptophyllum (Moq.) Nutt. ex S. Watson			AF
Chrysothamnus viscidiflorus (Hook.) Nutt.			PS
Cirsium undulatum (Nutt.) Spreng.			PF
Cleome serrulata Pursh			AF

Comandra umbellata (L.) Nutt.			PF
Coryphantha vivipara (Nutt.) Britton & Rose			PS
Crepis runcinata (E. James) Torr. & A. Gray			PF
Cryptantha cinerea (Greene) Cronquist			PF
Cryptantha minima Rydb.			AF
Deschampsia caespitosa (L.) P. Beauv.			PGC
Descurainia pinnata (Walter) Britton			AF
Distichlis stricta (Torr.) Rydb.			PGW
Elymus elymoides (Raf.) Swezey			PGC
Elymus lanceolatus (Scribn. & J. G. Sm.)			PGW
Elymus smithii (Rydb.) Gould			PGC
Equisetum laevigatum A. Braun	*yes*		AF
Ericameria nauseosa (Pall. ex Pursh) G. L. Nesom & G. I. Baird			PS
Eriogonum effusum Nutt.			PS
Hesperostipa comata (Trin. & Rupr.) Barkworth			PGC
Hordeum jubatum L.			PGC
Hydrophyllum sp			PF
Juncus arcticus Willd. var. *balticus* (Willd.) Trautv	*yes*		PGC
Juncus sp.			PGC
Juncus torreyi Coville	*yes*		PGC
Kochia scoparia (L.) Schrad.		I	AF
Koeleria macrantha (Ledeb.) Schult.			PGC
Lactuca serriola L.		I	AF
Lappula occidentalis (S. Watson) Greene			AF
Lepidium densiflorum Schrad.			AF
Liatris punctata Hook.			PF
Linum lewisii Pursh			PF
Lygodesmia juncea (Pursh) D. Don			PF
Medicago lupulina L.		I	AF
Mirabilis linearis (Pursh) Heimerl			PF
Mirabilis nyctaginea (Michx.) MacMill.			PF
Muhlenbergia asperifolia (Nees & Meyen ex Trin.) Parodi			PGW
Muhlenbergia cuspidata (Torr. ex Hook.) Rydb.			PGW

Musineon divaricatum (Pursh) Nutt. ex Torr. & A. Gray			PF
Nassella viridula (Trin.) Barkworth			PGC
Oenothera albicaulis Pursh			AF
Oenothera coronopifolia Torr. & A. Gray			PF
Oenothera curtiflora W. L. Wagner & Hoch			AF
Oenothera suffretescens (Ser.) W. L. Wagner & Hoch			PF
Opuntia cymochila Engelm. & Bigelow			PS
Opuntia polyacantha Haw.			PS
Oxytropis lambertii Pursh			PF
Oxytropis sericea Nutt.			PF
Panicum capillare L.			AGW
Panicum virgatum L.			PGW
Penstemon angustifolius Nutt. ex Pursh			PF
Picradeniopsis oppositifolia (Nutt.) Rydb.			PF
Plantago eriopoda Torr.			AF
Plantago patagonica Jacq.			AF
Poa arida Vasey			PGC
Poa pratensis L.		I	PGC
Poa secunda J. Presl			PGC
Polygonum ramosissimum Michx.			AF
Potentilla rivalis Nutt.	*yes*		AF
Psoralidium tenuiflorum (Pursh) Rydb.			PF
Ranunculus cymbalaria Pursh	*yes*		PF
Ratibida columnifera (Nutt.) Wooton & Standl.			PF
Rumex crispus L.		I	PF
Salsola australis R. Br.		I	AF
Schedonnardus paniculatus (Nutt.) Trel.			PGW
Schoenoplectus americanus (Pers.) Volkart ex Schinz & R. Keller	*yes*		PGC
Schoenoplectus tabernaemontani (K. C. Gmel.) Palla	*yes*		PGC
Scutellaria brittonii Porter			PF
Solidago canadensis L.			PF
Sophora nuttalliana B. L. Turner			PF
Spartina gracilis Trin.	*yes*		PGW

Sphaeralcea coccinea (Nutt.) Rydb.			PF
Sporobolus airoides (Torr.) Torr.			PGW
Sporobolus cryptandrus (Torr.) A.Gray			PGW
Symphyotrichum falcatum (Lindl.) G. L. Nesom			PF
Symphyotrichum falcatum (Lindl.) G. L. Nesom var. *crassulum* (Rydb.) G. L. Nesom			PF
Symphyotrichum lanceolatum (Willd.) G. L. Nesom var. *hesperium*			PF
Talinum parviflorum Nutt.			PF
Taraxacum officinale Weber ex F. H. Wigg.		I	PF
Thelesperma megapotamicum (Spreng.) Kuntze			PF
Tragopogon dubius Scop.		I	PF
Vicia americana Muhl. ex Willd.			PF
Viola nuttallii Pursh			PF
Vulpia octoflora (Walter) Rydb.			AGC
Xanthisma spinulosum (Pursh) D. R. Morgan & R. L. Hartm.			PF

APPENDIX D

SPECIES RECORDED AT PLC IN NON-FLOODED COMPETITION PLOTS

Nomenclature based on the Checklist of Vascular Plants of the Southern Rocky Mountain Region (Version 2, 2007) Neil Snow	Native/Introduced	Functional Type
Atriplex heterosperma Bunge	Introduced	Forb
Bromus inermis Leyss.	Introduced	Gramenoid
Bromus tectorum L.	Introduced	Gramenoid
Cirsium arvense (L.)	Introduced	Forb
Convolvulus arvensis L.	Introduced	Forb
Descurainia pinnata (Walter) Britton	Native	Forb
Distichlis stricta (Torr.) Rydb.	Native	Gramenoid
Elymus elongatus (Host) Runem.	Introduced	Gramenoid
Elymus smithii (Rydb.) Gould	Native	Gramenoid
Euphorbia esula L.	Introduced	Forb
Hordeum jubatum L.	Native	Gramenoid
Kochia scoparia (L.) Schrad.	Introduced	Forb
Lactuca serriola L.	Introduced	Forb
Malva neglecta Wallr.	Introduced	Forb
Phalaris arundinacea L.	Native	Gramenoid
Poa pratensis L.	Introduced	Gramenoid
Salsola australis R. Br.	Introduced	Forb

APPENDIX E

STUDENT PRE-SITE VISIT INTERVIEW QUESTIONS

Date:

Time:

Interviewer:

Interviewee:

Intro script: I am a researcher from UNC and will be asking you a few questions about mine reclamation to determine your perceptions and understanding about reclamation. Thank you for being willing to participate in this study. If you do not want to participate in the study you can choose to quit. You may also skip any questions you are not comfortable answering.

1. Do you know what the word reclamation means? If so, could you define it for me? (If the student does not know, define reclamation: The act or process of reclaiming - a restoration, as to productivity, usefulness, or health; the process of returning a disturbed site back to a functioning ecosystem through re-vegetation and soil conditioning.)
2. Tell me what you know about mine reclamation.
3. Do you think a damaged by mining area should be reclaimed?
4. What damage would an area mined for gravel experience?
5. Describe a healthy ecosystem in terms of plants, animals and soil characteristics.
6. What steps would you take to turn a mined site into a functional or healthy ecosystem?
7. How many years do you think it would take to turn a mined area into a healthy evironment?
8. Go ahead and bring out your picture you drew in class. Explain your drawing.
9. Why did you draw what you did?
10. Do you think the process of reclamation is beneficial?
11. Do you think the process of reclamation could be harmful?
12. What would happen if reclamation did not occur?
13. Are you aware of any areas near where you live where gravel mine reclamation is occurring?
14. Is there anything else you would like to add or questions you have for me?

Closure: Thank you, I appreciate your participating in this study. Would you fill out a short questionnaire on some general information about yourself? Thanks!

APPENDIX F

STUDENT POST-SITE VISIT INTERVIEW QUESTIONS

Date:

Time:

Interviewer:

Interviewee:

Intro script: I am a researcher from UNC and will be asking you a few questions about mine reclamation to determine your perceptions and understanding about reclamation. Thank you for being willing to participate in this study. If you do not want to participate in the study you can choose to quit. You may also skip any questions you are not comfortable answering.

1. Do you know what the word reclamation means? If so, could you define it for me? (If the student does not know, define reclamation: The act or process of reclaiming - a restoration, as to productivity, usefulness, or health; the process of returning a disturbed site back to a functioning ecosystem through re-vegetation and soil conditioning.)
2. Tell me what you know about mine reclamation.
3. Do you think a damaged by mining area should be reclaimed?
4. What damage would an area mined for gravel experience?
5. Describe a healthy ecosystem in terms of plants, animals and soil characteristics.
6. What steps would you take to turn a mined site into a functional or healthy ecosystem?
7. How many years do you think it would take to turn a mined area into a healthy environment?
8. Go ahead and bring out your picture you drew in class. Explain your drawing.
9. Why did you draw what you did?
10. Do you think the process of reclamation is beneficial?
11. Do you think the process of reclamation could be harmful?
12. What would happen if reclamation did not occur?
13. Are you aware of any areas near where you live where gravel mine reclamation is occurring?
14. Describe your trip to the Poudre Learning Center.
15. How did this trip affect your ideas about reclamation?
16. Is there anything else you would like to add or questions you have for me?

Closure: Thank you, I appreciate you participating in this study. Thanks!

APPENDIX G

IRB APPROVAL

Sept. 19, 2010

STUDENT'S COPY

TO: Maria Lahman

FROM: Teresa McDevitt, Member
UNC Institutional Review Board

RE: Omnibus Review of an Expedited Proposal, Assessing attitude changes in high school students towards mining reclamation sites, submitted by Michael Schiebout, advisor Maria Lahman

First Consultant: The above proposal is being submitted to you for an omnibus expedited review. Please review the proposal in light of the Committee's charge and direct requests for changes directly to the researcher or researcher's advisor. If you have any unresolved concerns, please contact Maria Lahman, SRM. When you are ready to recommend approval, sign this form and return to me.

I recommend approval as is. [signature] 9-20-10
Signature of First Consultant Date

The above referenced prospectus has been reviewed for compliance with HHS guidelines for ethical principles in human subjects research. The decision of the Institutional Review Board is that the project is approved as proposed for a period of one year: 9/28/2010 to 9/28/2011

[signature] 9/28/2010
Teresa McDevitt, Member Date

Comments:

See revised consent form; principal's permission; emailed clarifications