DISSERTATION

RESTORING PLANT AND INSECT COMMUNITY DIVERSITY IN A CRESTED WHEATGRASS DOMINATED AREA

Submitted by

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ABSTRACT

RESTORING PLANT AND INSECT COMMUNITY DIVERSITY IN A CRESTED WHEATGRASS DOMINATED AREA

Changing climate and plant invasion are having negative impacts on biodiversity in rangeland ecosystems. Crested wheatgrass (Agropyron cristatum [L.] Gaertn.), a nonnative species, has been used to improve livestock forage on rangelands. However, this nonindigenous species can result in reduced native plant diversity. I conducted a study to determine the most successful native plants (southern, central, or northern US ecotypes) for use in restoration of crested wheatgrass stands and to examine if increased seed rain of forbs and shrubs will result in increased establishment of these life forms. In Fall 2012, I seeded a mix of native plants in a completely randomized design in Larimer County, CO. I tested 6 seed mix treatments containing southern, central, or northern US ecotypes: grass only, grass and forb, grass and shrub, grass, forb and shrub, or grass with bird perches to provide a natural source of seed rain, and unseeded controls. I sampled aerial cover of seeded and unseeded plants from 2013-2015. In each year, I observed native plants from southern areas had more cover than native plants from northern areas. Promoting seed rain via bird perches had no effect on forb and shrub cover. I found a high cover of non-native forbs in plots seeded with grass only. Establishing native plants in degraded rangelands is an important approach for restoring community diversity, and using ecotypes adapted to future conditions may help improve seeding success. Also, declines in plant species diversity led to decreases in insect diversity. In my study, I

proposed that greater plant diversity would increase the number of herbivorous insects because insect communities depend on the availability of plants as basic resources for their growth. To examine the effects of plant richness on insect richness and abundance I sampled the insects by using three different techniques (drop trap, pitfall trap and pan trap) from the original restoration vegetation study. My results in this experimental study show that plant richness did not support the total number of insects. The total abundance of all insects did not differ significantly across treatments from data collected by pitfall trap and pan trap techniques. However, the order Homoptera was the most abundant group found in the verity of plant species treatment (n=15) from drop-trap data.

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DEDICATION

TO THE SPIRITS OF MY

FATHER

AND

MOTHER

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Chapter 1

Restoring Community Diversity with Native Plants in a Crested Wheatgrass Dominated Area

Introduction

The composition and structure of rangelands in western North America have changed over the past 150 years. Introduction and expansion of nonindigenous species have increased causing decreases in native species diversity (D'Antonio and Vitousek 1992). Establishment of nonindigenous species such as crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.) has been high relative to native species establishment (Monsen 2004). As a result, nonnative species have become dominant in many areas throughout western North America.

Crested wheatgrass is a long-lived perennial bunch grass, which was introduced by the U.S. Dept. of Agriculture from Russia and Siberia in 1898 (Westover et al. 1932). This introduced perennial grass has since been seeded throughout much of western North America including the Great Plains and Intermountain region, and has become dominant on 6-11 million hectares of the rangeland in North America (Lesica and DeLuca 1996).

The reasons for crested wheatgrass introduction into the USA was to control erosion, increase live forage, control weeds and reduce wildfire (Lorenz 1986). Crested wheatgrass has characteristics that have contributed to its widespread use in the past. These include ease of planting and establishment (Love 1932), high seed availability and low cost, tolerance of harsh conditions such as drought, extreme temperatures and disease (Hull and Klomp 1966).For example, many disturbed sites were seeded to crested wheatgrass because of its ease of establishment in those conditions (Marlette and Anderson 1986). Crested wheatgrass has also been planted to improve forage resource for grazing animals (Knowles and Buglass 1980; Broersma et al. 2000).

Although the introduction of crested wheatgrass has often been considered beneficial (especially historically), there are several factors that may create significant long term declines in biological diversity. Few native plants are able to invade crested wheatgrass plantings (Looman and Heinrichs 1973; McHenry and Newell 1947; Wilson 1989) resulting in virtual monocultures that persist for at least 40-50 years (Marlette and Anderson 1986; Box 1986; Smoliak et al. 1967). The reduction of plant diversity in crested wheatgrass rangelands undoubtedly results in lower diversity of invertebrate and vertebrate animals as well (Gaston 1991).

Despite widespread and early concern over introduced exotic species (Elton 1958), few studies have sufficiently quantified the impacts of these introductions on native ecosystems (Parker et al. 1999). Some studies indicate that crested wheatgrass has negative impacts on ecosystems such as loss of native biodiversity and community structure (Broersma et al. 2000; Marlette and Anderson 1986). Crested wheatgrass has several characteristics that contribute to its competitiveness with native vegetation when planted in mixtures with native species (Heinrichs and Bolton 1950; Schuman et al. 1982). For example, at the seedling stage, crested wheatgrass has an advantage over some native plants due to its ability to capture nutrients and water (Bakker and Wilson 2001). Another example of negative impact of crested wheatgrass on native species has been shown when crested wheatgrass was grown with big sagebrush (*Artemisia tridentata* Nutt.). The ability of crested wheatgrass to rapidly extract soil water during the same period that sagebrush requires this resource “heavily inhibits its growth” (Cook and Lewis 1963). Few investigators (e.g. Clements 1935) reported the lack of crested wheatgrass persistence on rangelands where it had been introduced because of intense competition from indigenous species. However, it is now recognized that crested wheatgrass has the ability to reseed itself well and spread in areas to which it is adapted (Weintraub 1953). Other studies suggest that crested wheatgrass has a long term negative impacts on soil by creating a more exposed surface (Wilson 1989) and decreasing soil resource availability (Dormaar et al. 1979; Eissenstat and Caldwell 1988; Christian and Wilson 1999; Whalen et al. 2003). This exposed soil increases rates of erosion (Dormaar et al 1995) resulting in lower soil quality (Deluca and Keeney 1994).

In western North America there is a desire and need to convert large areas of crested wheatgrass into more diverse native plant communities. Native plants are important for improving wildlife habitat and creating species diversity in disturbed ecosystems. Converting crested wheatgrass to native- plant dominated communities requires control methods such as chemical treatment of crested wheatgrass and native plant establishment (Pellant and Lysne 2005). Many studies have shown that native species establishment has several benefits in disturbed areas (Knops et al. 1999, Tilman, 1997, 1999, Biondini 2007, Piper 1995). Some direct effects to plant community structures include resistance to invasive species (Naeem et al. 2000), improved ecosystem stability (Stevens 1994), and increased plant biomass (Knops et al. 1999). In addition, some indirect effects include decreased spread of fungal diseases (Mitchell et al. 2002), increased richness and structure of insect communities (Reynolds 1980), and providing habitat for birds and other wildlife (Pellant and Lysne 2005). Clearly there is a need to develop methods for restoring crested wheatgrass dominated plant communities to systems dominated by native plants to provide these benefits. One challenge in doing this is the uncertainty of determining what native plant species to include given climate change and current prolonged drought in many parts of western North America.

A number of studies have shown that the next century will be characterized by shifts in global weather patterns and changes in climate regions (Watson et al. 2001; Munasinghe and Swart 2005; Harris et al. 2006; IPCC 2007; Min et al. 2011; Dai 2013; Eade et al. 2014; Butterfield et al. 2017; Jones et al. 2017). Although future climate change scenarios vary in intensity of impact, all predictions indicate changes in weather patterns, increases in mean temperatures, changes in patterns of precipitation, and increasing sea level (Watson et al. 2001; Kane et al. 2017). For example, in Colorado, temperatures have increased by approximately 1^{O}C between 1977 and 2006 (The Western Water Assessment for the State of Colorado, 2011). Projections indicate that summer monthly temperatures will be warmer than the hottest 10% of summers that occurred between 1950 and 1999 (Ray et al. 2008; Clow 2010). In the USA, recent work on the changes in biophysical regions found that shifts in temperature, moisture and soil conditions will be seen in many areas (Saxon et al. 2005). According to the Arctic Climate Impact Assessment (ACIA 2004; Stroeve 2012), a significant change is already being detected in high northern latitudes. These changes are unpredictable in timing and intensity. Since the most recent glacial period ended, the climate has been warming and drying. There is now unequivocal evidence that the earth is warming faster than any other time in recorded history (IPCC 2007; Polley et al. 2013). The climate across many areas is expected to become increasingly warmer and drier during this century (Kling et al. 2003; IPCC 2013). Furthermore, the recent historical record illustrates the complexity of the climate due to spatial and seasonal variability in temperature trends, as well as differences in the daytime and nighttime temperatures and their recent trends. To reach ecosystem stability with climate change, we should think about restoring plant community diversity.

Ecological restoration in this project focuses on re-establishing some species that are able to adapt to changes in climate, considering that future temperatures are expected to increase and many areas will be warmer and drier. In Colorado, it is predicted that temperatures will increase by 1.4^{o} C by2025 and 2.2^{o} C by 2050 (Ray et al. 2008). In order to identify specific plant communities that are drought and heat tolerant, a variety of native plants were used in this study.

There is growing evidence that plants and animals migrate in response to climate change (Ray et al. 2008). As the climate changes, certain plant populations will migrate to areas with more suitable climate. In reality, plant populations may take years or decades to move substantial distances (Huntley and Birks 1983; Ritchie and Macdonald1986; Delcourt and Delcourt 1987; King and Herstrom 1997). Moreover, plant populations must migrate through the landscapes to avoid climate change impacts (Pitelka 1997). A number of studies indicated that plant populations of the American southwest have changed since the climate became warmer and drier. Changes in populations of plants in the American southwest have been shown in pollen and fossil records (Betancourt et al. 1990; Miller and Wigand 1994).

Plants typically move as seeds, dispersed by animals and wind, to new habitats (Davis 1998). One method to encourage seed rain, and thereby increase vegetation cover and richness in disturbed rangeland, is the use of artificial bird perches. Artificial perches may attract birds into an area and enhance seed dispersal (McDonnell and Stiles 1983; McClanahan and Wolfe 1993). Consequently, bird perches remain a potential tool for accelerating ecological succession and restoring degraded areas. Several studies have concluded that the presence of forest seeds, seedling shrubs and trees was a result of seed deposition by birds (Guevara et al. 1986; Toh et al. 1999). For example, in temperate pastures (McDonnell and Stiles 1983; McDonnell 1986) and temperate mined sites (McClanahan and Wolfe 1993), bird perches were constructed and left standing several years that led to increased seed abundance and diversity of bird-dispersed plants under perches. Consequently, in order to determine the effectiveness of bird-dispersal for establishing plants in reclaimed rangelands, bird- attracting structures such as artificial perches were used in this study.

Attempts to establish native grasses, forbs and shrubs are important for restoration projects. Although grasses have been widely used in many projects to restore degraded rangelands in North America, forbs and shrubs are reported to improve conditions of degraded areas by providing nesting cover for songbirds as well as for pygmy rabbits (Thines et al. 2004). In addition, threatened sage grouse are dependent upon native forbs and shrubs to survive and reproduce. For example, the decline of sage-grouse populations in western North America has been associated with loss of habitat diversity of native sagebrush rangelands (Johnson and Braun 1999; Crawford et al. 2004). Another example has been illustrated by Thines et al. (2004) that pygmy rabbit populations have also decreased due to declines of big sagebrush (*Artemisia tridentata* Nutt), which is a required component of its habitat. Numerous studies indicate that grasses are successful establishment species due to their tolerance of harsh conditions such as heat and drought. These grasses have narrow linear leaves that lose less water than larger leaves (Xu et al. 2009) and have deep rooting systems (Weaver 1954). Another important characteristic of grasses is that they are strong competitors. For example, some grasses accumulate a large amount of biomass each growing season and are dispersed by wind or animals (Monsen 2004).

However, planting only grasses in degraded ecosystems may not be appropriate when management goals seek to increase native biodiversity. Increasing seeded species diversity by including native forbs and shrubs will increase the types of food available to a wide variety of herbivores at different times of the year, and the number of foraging and nesting niches available (Barnes 1998). Many native forbs and shrubs are slow-growing, which means they will take longer to reach maturity and bloom, but sowing a more diverse seed mixture can benefit wildlife (Martin and Nelson 1951).

Because the establishment of native plants in areas dominated by crested wheatgrass is challenging, I established a field study to test various approaches for establishing native plants from seeds in an area where crested wheatgrass had been reduced by herbicide application. In this study, I examined the use of native species from warmer and dryer regions relative to cooler and moister regions, the ability of native shrubs and forbs to colonize in areas seeded only with grasses, and the impact of artificial bird perches for recruitment of native plant diversity to accelerate the recovery of wildlife habitat.

Hypotheses

Hypothesis 1: The establishment of native plant species that have the ability to tolerate dry and warm conditions (southern species) will be more successful (have more cover) than similar species adapted to cool dry or cool mesic conditions (northern species).

Hypothesis 2: During the first several years after seeding, forbs and shrubs will not colonize areas seeded only with grass.

Hypothesis 3: Artificial perches will increase seedling establishment of native forb and shrub species.

MATERIALS AND METHODS

Site description

The site for this study is owned by Colorado State University (CSU) and is located north of Fort Collins, Colorado, in Larimer County (UTM 48T 505998.50, 4506234.54). The 127-ha property is used for research and is managed by the Forest and Rangeland Stewardship Department at CSU. In the 1950's and 1960's, much of the property was seeded with non-native forage grasses, which still dominate today. A portion of the west half of the property (~3 ha) was used in this study as part of a larger effort to convert exotic crested wheatgrass to native vegetation. Soil at the site is dominated by Kim Loam with 1-3 percent slopes (Web Soil Survey-Larimer County Area-NRCS 2010) and elevation ranges from 1500 to 1600 m. Mean annual precipitation that was obtained from the weather station at the site for 2013, 2014, and 2015, the years this study took place, was 300-400 mm. The monthly average temperature and monthly total precipitation on the site for the three years (2013, 2014, and 2015) are shown in Table 1.

Table1. Monthly average temperature (^{o}C) and total precipitation (mm) data (Campbell Scientific Weather Stations CR1000) for the years of the study (2013, 1014 and 2015).

	Average temperature ^{O}C			Total Precipitation (mm)			Average Temperature ^{O}C	Average Precipitation (mm)
Month	2013	2014	2015	2013	2014	2015	1960-2012	1960-2012
January	-1.93	-0.65	-0.29	0.25	4.80	9.40	-1.59	538.73
February	-1.69	-4.07	0.79	3.30	13.20	12.45	0.49	540.77
March	2.43	3.17	5.74	10.16	24.39	3.30	4.38	1800.09
April	4.70	8.48	8.08	14.22	6.60	53.34	9.03	2488.44
May	13.22	12.45	10.30	48	84.83	138.94	13.88	3377.18
June	20.05	17.26	19.17	8.64	22.86	92.71	18.95	2693.92
July	21.39	21.14	20.22	29.46	75.70	69.34	22.26	2344.67
August	21.48	19.90	20.91	3.30	9.40	20.07	20.95	1913.38
September	17.27	16.19	18.73	139.70	27.43	0.00	16.11	1770.13
October	7.52	11.11	11.55	31.50	29.72	49.27	9.96	1506.98
November	2.79	1.27	2.10	3.05	16.51	22.36	3.38	933.45
December	-3.15	-1.48	-1.48	3.05	0.76	6.35	-1.11	650.75
Growing season	15.09	15.22	15.57	274.8	256.5	423.7	15.88	16094.71
Average / total	8.67	8.73	9.65	294.6	316.2	477.5	9.72	1713.21

Site preparation

In mid-June, 2012, the site was sprayed using a PTO-driven, tractor-mounted sprayer. Glyphosate (2.5 kg ai ha^{-1}), aminocyclopyrachlor (0.02 L ai ha^{-1}), spray-grade ammonium sulfate (0.7 kg ha^{-1}) and a surfactant were applied using water as the carrier in an attempt to kill all plants at the site including the dominant crested wheatgrass. In October, 2012, the entire area was harrowed twice. Harrowing was conducted to remove dead vegetation and prepare a seed bed. In November, 2012, it was apparent that much crested wheatgrass remained alive, so a second dose of herbicide application (1.26 kg ai ha^{-1} glyphosate + 0.56 kg ha^{-1} spray grade ammonium sulfate + surfactant) was applied.

Experimental Design and Treatment description

Experimental Design

Forty two plots, 30- x 13.4-m, were established at the site with 5-m buffer zones between all plots. The site was seeded in December 2012. Seven replicates each of five seeding treatments plus unseeded control plots were arranged in a completely randomized design (Figure 1).

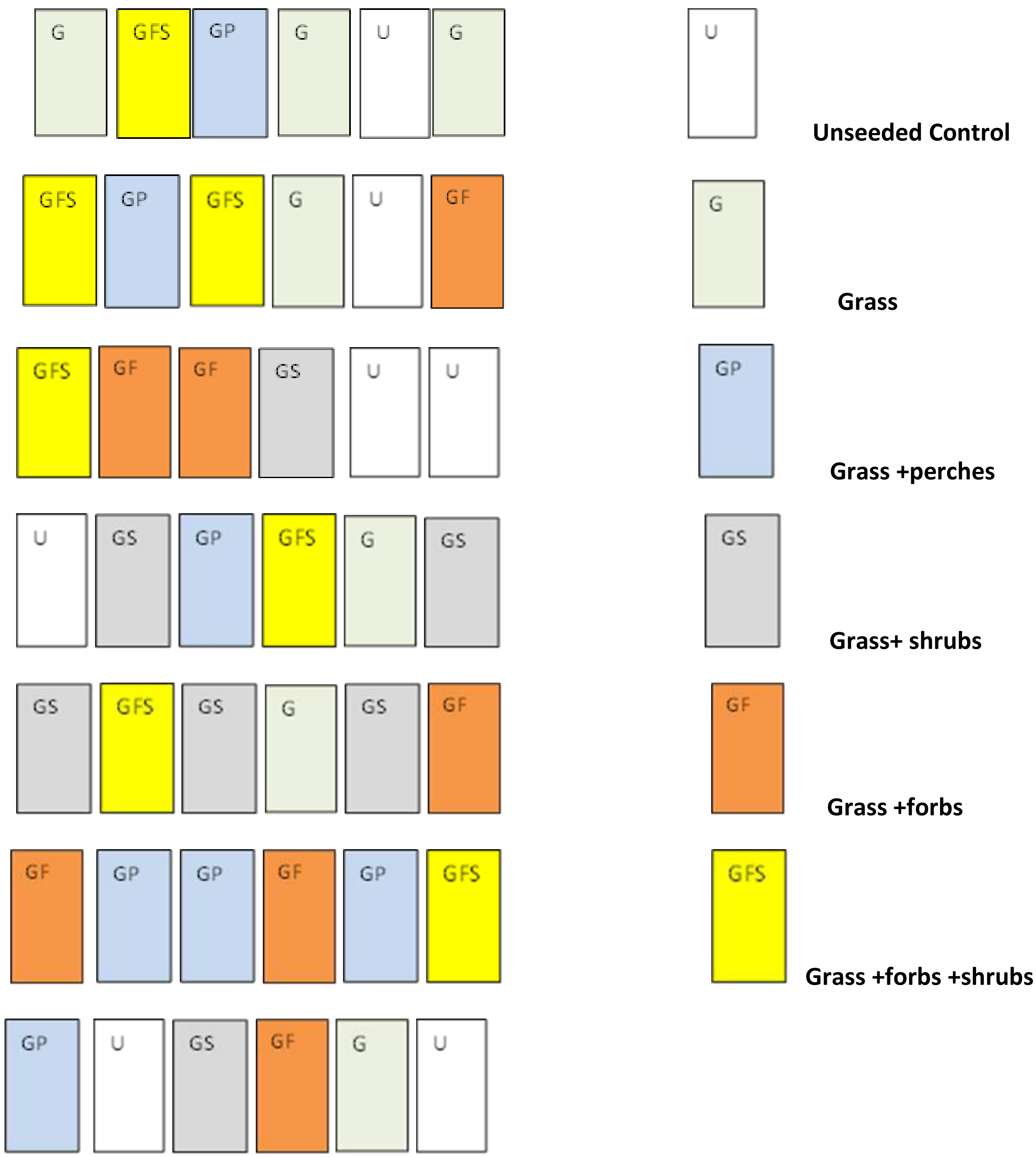

Figure 1: Layout of 30-x13.4-m experimental plots in Larimer County, Colorado, showing relative locations of seven replicates of each of five seeding treatment plots: grasses (G), grasses + forbs (GF), grasses + forbs + shrubs (GFS), grasses + shrubs (GS), grasses + perches (GP) and unseeded control (U).

Treatment description

Treatments were seeded with: 1) grass only (G), 2) grasses and forbs (GF), 3) grasses, forbs and shrubs (GFS), 4) grasses and shrubs, 5) grass and perches placed in the plot to attract birds as seed dispersers (GP), and 6) unseeded control plots without perches (U). Each plot was seeded at a rate of 350 pure live seeds m^2. The seed mixtures included native plant species with seed origins predominantly south or north of the study site. Seed source location as indicated by seed companies was used to determine seed origin as from “north” (e.g. Montana), “center” (e. g. Colorado) or from “south” regions (e. g. New Mexico) (USDA, NRCS 2015). All seeds for the study were purchased from Granite Seed Company, Western Native Seed, Southwest Seed, Arizona Native Seed Source, Stover, Paul Allen, S&S Seed and Sunmark Seeds. For the grass mix, 29 grass species were sown (Table 1). For the forb mix, 28 forb species were sown (Table 2). For shrubs, 22 shrub species were sown (Table 3). All species were native to western USA (USDA 2013).

Seeding Method

Medium and most large-seeded species were drill seeded and species with small or very large seeds were broadcast seeded (Appendix 1). Seeding was conducted in early-December of 2012. A Truax drill (Truax Company, INC, Minneapolis, MN, USA) was used for drill-seeding (Figure 2-1). Broadcast seeding was done using Earthway® hand-crank spreaders (Figure 2-2) or by hand for some large seeds that were too large to use with the drill. Seven bird perches were placed in each of seven GP treatment plots after seeding the plot. Perches consisted of metal posts about 1-m high with single strands of fence wire strung between posts for birds to perch on (Figure 2-3). The height of the wire on the posts was varied along the length of each perch to provide a variety of perch heights. A number of studies have shown that different height of perches enhance seed rain under perches (Press 1995; Holl 2002; Heelemann et al. 2012)

Table 2: List of grass species used in seed mixes that were planted in replicated test plots. Treatments were applied in a randomized complete design. Treatments were: grass (G), grass perches (GP), grass forb (GF), grass shrub (GS) and grass forb shrub (GSF). Seeding rates for each species are shown as pure live seeds (PLS) m^{-2} . Each seed mix contained a total of 350 PLS) m^{-2}.

			Seeding Treatment and Rate(PLS/m^2)				
Common name	Genus	Species	G	GP	GF	GS	GSF
Purple threeawn	*Aristida*	*pupurea* Nutt.	11.6	11.6	5.8	5.8	3.9
Sand bluestem	*Andropogon*	*hallii* Hack.	11.6	11.6	5.8	5.8	3.9
Big bluestem	*Andropogon*	*gerardii* Vitman.	11.6	11.6	5.8	5.8	5.8
Cane bluestem	*Bothriochloa*	*barbinodis*(Lag). Herter	11.6	11.6	5.8	5.8	5.8
Sideoats grama	*Bouteloua*	*curtipendula(*Michx.)	11.6	11.6	5.8	5.8	5.8
Blue grama	*Bouteloua*	*gracilis(*Willd.ex Kunth*)*	11.6	11.6	5.8	5.8	5.8
Galleta	*Pleuraphis*	*jamesii* Torr*.*	11.6	11.6	5.8	5.8	5.8
Little bluestem	*Schizachyrium*	*scoparium*(Michx.)Nash	11.6	11.6	5.8	5.8	5.8
Buffalograss	*Bouteloua*	*dactyloides*(Nutt.)J	11.6	11.6	5.8	5.8	5.8
Prairie sandreed	*Calamovilfa*	*longifolia*(Hook.)	11.6	11.6	5.8	5.8	5.8
Canada wildrye	*Elymus*	*canadensis* L.	11.6	11.6	5.8	5.8	5.8
Squirreltail	*Elymus*	*elymoides*(Raf.)Swezey	11.6	11.6	5.8	5.8	5.8
Thickspike wheatgrass	*Elymus*	*lanceolatus(*Scribn.& J.G.Sm.)Gould	11.6	11.6	5.8	5.8	5.8
Slender wheatgrass	*Elymus*	*trachycaulus*(Link)Gould ex Shinners	11.6	11.6	5.8	5.8	5.8
Needle and thread	*Hesperostipa*	*comata*(Trin. &Rupr.)Barkuorth	11.6	11.6	5.8	5.8	5.8
Prairie Junegrass	*Koeleria*	*macrantha*(Ledeb.)Schult	11.6	11.6	5.8	5.8	5.8
Green needlegrass	*Nassella*	*viridula*(Trin.)Barkuorth	11.6	11.6	5.8	5.8	5.8
Western wheatgrass	*Pascopyrum*	*smithii*(Rydb.) Á. Löve	11.6	11.6	5.8	5.8	5.8
Sandberg bluegrass	*Poa*	*secunda* J. Presl	11.6	11.6	5.81	5.8	5.8
Bluebunch wheatgrass	*Pseudoroegneria*	*spicata*(Pursh) Á. Löve	11.6	11.6	5.81	5.8	5.8
Sixweeks fescue	*Vulpia*	*octoflora*(Walter) Rydb.	11.6	11.6	5.8	5.8	5.8
Indian ricegrass	*Achnatherum*	*hymenoides*(Roem. & Schult.) Barkworth	11.6	11.6	5.8	5.8	5.8

			Seeding Treatment and Rate(PLS/m^2)				
Common name	Genus	Species	G	GP	GF	GS	GSF
Saltgrass	*Distichlis*	*spicata* (L.) Greene	11.6	11.6	5.8	5.8	5.8
Plains lovegrass	*Eragrostis*	*Intermedia* Hitchc.	11.6	11.6	5.8	5.8	5.8
Scratchgrass	*Muhlenbergia*	*asperifolia*(Nees & Meyen ex Trin.) Parodi	11.6	11.6	5.8	5.8	5.8
switchgrass	*Panicum*	*virgatum* L.	11.6	11.6	5.8	5.8	5.8
Large-spiked plains bristlegrass	*Setaria*	*macrostachya* Kunth	11.6	11.6	5.8	5.8	5.8
Alkali sacaton	*Sporobolus*	*airoides* (Torr.) Torr.	11.6	11.6	5.8	5.8	5.8
Sand dropseed	*Sporobolus*	*cryptandrus* (Torr.) A. Gray	11.6	11.6	5.8	5.8	5.8
	# Grass=29						

Table 3: List of forb species used in seed mixes that were planted in replicated test plots. Treatments were applied in a randomized complete design. Treatments were: grass (G), grass perches (GP), grass forb (GF), grass shrub (GS) and grass forb shrub (GSF). Seeding rates for each species are shown as pure live seeds (PLS) m^{-2}. Each seed mix contained a total of 350 PLS) m^{-2}.

			Seeding Treatment and Rate(PLS/m^2)				
Common name	Genus	Species	G	GP	GF	GS	GSF
blanketflower	*Gaillardia*	*aristata* Pursh	0	0	6.02	0	4.01
hairy false goldenaster	*Heterotheca*	*villosa* (Pursh) Shinners	0	0	6.02	0	4.01
dotted blazing star	*Liatris*	*punctata* Hook.	0	0	6.02	0	4.01
plains zinnia	*Zinnia*	*grandiflora* Nutt.	0	0	0.24	0	0.16
tarragon	*Artemisia*	*dracunculus* L.	0	0	6.02	0	4.01
textile onion	*Allium*	*textile* A. Nelson & J.F. Macbr.	0	0	6.02	0	4.01
Drummond's milkvetch	*Astragalus*	*drummondii* Douglas ex Hook.	0	0	6.02	0	4.01
Rocky Mountain beeplant	*Cleome*	*serrulata* Pursh	0	0	6.02	0	4.01
black samson	*Echinacea*	*angustifolia* DC.	0	0	6.02	0	4.01
Utah sweetvetch	*Hedysarum*	*boreale* Nutt.	0	0	9.5	0	6.33
common sunflower	*Helianthus*	*annuus* L.	0	0	6.02	0	4.01
silvery lupine	*Lupinus*	*argenteus* Pursh	0	0	2.53	0	1.68
Pennsylvania smartweed	*Polygonum*	*pensylvanicum* L.	0	0	6.02	0	4.01
Fendler's meadow-rue	*Thalictrum*	*fendleri* Engelm. ex A. Gray	0	0	6.02	0	4.01
stiff greenthread	*Thelesperma*	*filifolium* (Hook.) A. Gray	0	0	6.02	0	4.01
crested pricklypoppy	*Argemone*	*polyanthemos* (Fedde) G.B. Ownbey	0	0	9.8	0	6.54
lambsquarters	*Chenopodium*	*album* L.	0	0	9.8	0	6.54
white prairie clover	*Dalea*	*candida* Michx. ex Willd.	0	0	6.02	0	4.01
purple prairie clover	*Dalea*	*purpurea* Vent.	0	0	6.02	0	4.01
sanddune wallflower	*Erysimum*	*capitatum* (Douglas ex Hook.) Greene	0	0	6.02	0	4.01
tansyleaf tansy aster	*Machaeranther*	*tanacetifolius* (Kunth) Nees	0	0	6.02	0	4.01
tufted evening primrose	*Oenothera*	*caespitosa* Nutt.	0	0	6.02	0	4.01
purple locoweed	*Oxytropis*	*lambertii* Pursh	0	0	6.02	0	4.01
broadbeard beardtongue	*Penstemon*	*angustifolius* Nutt. ex Pursh	0	0	6.02	0	4.01
upright prairie coneflower	*Ratibida*	*columnifera* (Nutt.) Wooton & Standl.	0	0	6.02	0	4.01
scarlet globemallow	*Sphaeralcea*	*coccinea* (Nutt.) Rydb.	0	0	6.02	0	4.01
prairie spiderwort	*Tradescantia*	*occidentalis* (Britton) Smyth	0	0	4.04	0	2.7
hoary verbena	*Verbena*	*stricta* Vent.	0	0	6.02	0	4.01
	#Forbs=28						

Table 4: List of shrub species used in seed mixes that were planted in replicated test plots. Treatments were applied in a randomized complete design. Treatments were: grass (G), grass perches (GP), grass forb (GF), grass shrub (GS) and grass forb shrub (GSF). Seeding rates for each species are shown as pure live seeds (PLS) m^{-2}. Each seed mix contained a total of 350 PLS) m^{-2}.

			Seeding Treatment and Rate(PLS/m^2)				
Common name	Genus	Species	G	GP	GF	GS	GSF
Yellow rabbitbrush	*Chrysothamnus*	*viscidiflorus*(Hook.) Nutt.	0	0	0	6.74	4.5
Rubber rabbitbrush	*Ericameria*	*nauseosa*(Pall. ex Pursh) G.L. Nesom & Baird	0	0	0	4.55	3.03
Winterfat	*Krascheninnikovia*	*lanata*(Pursh) A. Meeuse & Smit	0	0	0	11.39	7.59
Greasewood	*Sarcobatus*	*vermiculatus*(Hook.) Torr.	0	0	0	7.66	5.11
Prairie sagewort	*Artemisia*	*frigida* Willd.	0	0	0	7.66	5.11
White sagebrush	*Artemisia*	*ludoviciana*Nutt.	0	0	0	7.66	5.11
Wyoming big sagebrush	*Artemisia*	*tridentata*Nutt.	0	0	0	3.37	2.25
Saskatoon serviceberry	*Amelanchier*	*alnifolia*(Nutt.) Nutt. ex M. Roem.	0	0	0	11.37	7.58
Utah serviceberry	*Amelanchier*	*utahensis*Koehne	0	0	0	8.12	5.41
Fourwing saltbush	*Atriplex*	*canescens*(Pursh) Nutt.	0	0	0	11.37	7.58
Gardner's saltbush	*Atriplex*	*gardneri*(Moq.) D. Dietr.	0	0	0	7.66	5.11
Alderleaf mountain mahogany	*Cercocarpus*	*montanus*Raf. var. montanus	0	0	0	7.65	5.1
Chokecherry	*Prunus*	*virginiana* L.	0	0	0	9.77	6.51
Bitterbrush	*Purshia*	*tridentata*(Pursh) DC.	0	0	0	11.37	7.58
Skunkbush sumac	*Rhus*	*trilobata*Nutt.	0	0	0	7.66	5.11
Catclaw acacia	*Acacia*	*greggii*A. Gray	0	0	0	1.45	0.97
Honey mesquite	*Prosopis*	*glandulosa*Torr.	0	0	0	6.91	4.6
Soapweed yucca	*Yucca*	*glauca*Nutt.	0	0	0	11.37	7.58
Sand sagebrush	*Artemisia*	*filifolia*Torr.	0	0	0	7.66	5.11
Broom snakeweed	*Gutierrezia*	*sarothrae*(Pursh) Britton & Rusby	0	0	0	1.58	1.06
Golden currant	*Ribes*	*aureum*Pursh	0	0	0	7.85	5.23
Wax currant	*Ribes*	*cereum*Douglas	0	0	0	7.65	5.11
	#Shrubs=22						

Figure 2-1 Drill-seeding equipment that was used for seeding seed mixtures in replicated study plots**.**

Figure 2-2**:** Earthway® hand-crank spreaders used for sowing seed mixtures in replicated study plots.

Figure 2-3: Bird perches made from steel T-posts and wire used in some of the study plots to test input of seeds via bird perching.

Data Collection

Vegetation Sampling

Data was collected to measure aerial cover of seeded and unseeded plant species and to measure density of seeded species. Cover for all species (seeded and not seeded) in the plots was measured in August of each year (2013, 2014 and 2015) using a point-intercept method. Eight-12 m transects were placed at regular intervals across each plot and vegetation cover by species was measured every meter along each transect. Relative cover for each species was calculated based on the percentage of overall cover for each species in each plot.

Density of seeded species was measured in August, 2013. However, density was not measured in subsequent years because of high cover and the difficulty of counting plants. Density was measured in 2013 by using 8 cover frames (25- x 75-cm) randomly located in each plot (Figure 4). The number of seeded grasses, forbs and shrubs were counted by species in each frame.

Figure 4- Cover Frame (25- x 75-cm) used to estimate the density of seeded species for each plot.

Statistical Analysis

Analysis of variance was conducted using SAS 9.3 (SAS Institute INC, Cary, NC, USA, 2011) to examine the effect of treatments on cover and density of seeded species. The Kenward-Rogers denominator degrees of freedom method was used for unequal variances. Relative cover was calculated by dividing the total absolute cover of each species in each plot by the total plant cover for the plot. Seeded species density was converted to number of individuals per square meter by dividing the total number of each species encountered within the frame cover by the area of the frame. Response variables were grouped by seed source region (north, central, south), lifeform (grass, forb, shrub), and nativity to North America (native or non-native). When necessary, values were transformed to satisfy the normality assumptions by using square root transformation. Significance was determined at α =0.05.

Results

Based on the weather data collected at the site for this study (2013-2015), total annual average temperature increases slightly from 2013-2015 by 1 ^{o}C. Also, total annual perception increased from 2013 to 2014 by 21 mm and from 2014 to 2015 by 162mm.

Hypothesis 1: Southern species will have greater relative cover than northern species

Analysis showed statistical differences in cover between seeded southern and seeded northern species in 2013, 2014 and 2015 (p= 0.0001) (Figure 5). Southern species cover was significantly greater than northern species cover in all three years (2013-2015). The southern native Purple threeawn (*Aristida purpurea*) had high mean cover during all three years. Additionally, unseeded species (native and non-native to North America) was measured and the analysis showed that unseeded species increased from 2013 to 2014 and from 2014 to 2015. In 2013, all the shrub species that were measured in the plots were species that had been seeded, with rubber rabbitbrush (*Ericameria nauseosa*) dominating shrub cover in 2013 and 2014.

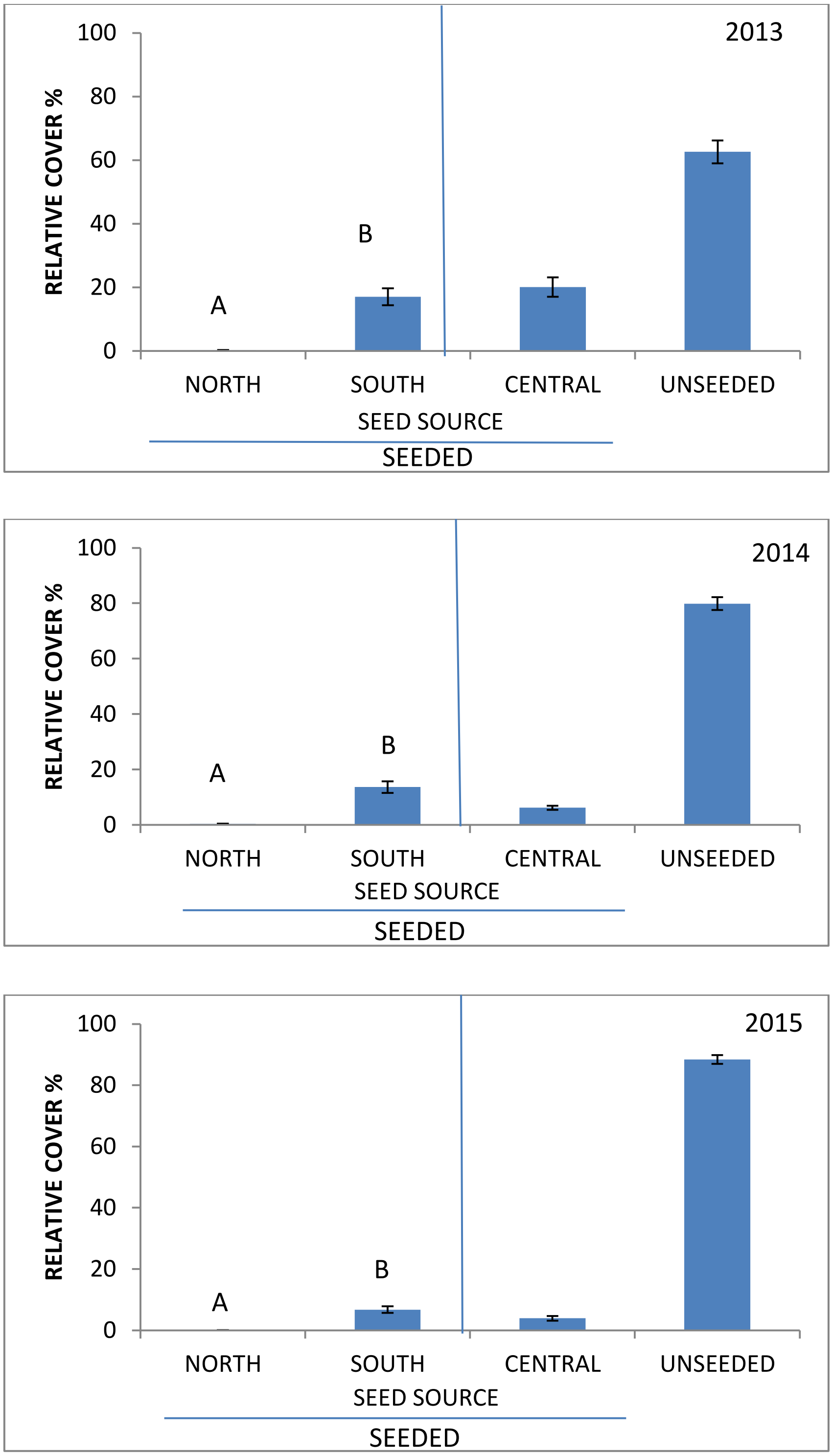

Figure 5: Mean relative cover (%) of seeded species by region of seed origin for 2013, 2014, and 2015. Thin bars represent standard error of the mean. Bars with different letters indicate statistically significant differences (p<0.05) using T-test. Vertical lines shown in the figure indicates that the statistical comparison is only between northern and southern species.

Hypothesis 2: Plots seeded with only grass species will not have any forbs or shrubs during the first three years after seeding (total forb and shrub cover = 0, and total seeded forb and shrub density=0).

To test this hypothesis, I analyzed total forb and shrub relative cover in the grass treatment (without perches) for each year after seeding. Additionally, I analyzed total combined forb and shrub density in the grass only treatment in 2013. Total combined forb and shrub relative cover values were significantly greater than zero in grass-only treatment for all three years (in 2013, p= <.0003, in 2014 p= <.000 and in 2015, p= 0.0013). This analysis showed that forbs and shrubs readily colonized the grass-only treatment during the first three years (Figure 6). Mean relative cover of forbs (native and non-native) was numerically higher in 2013 (63%) compared to 2014 (30%) and 2015 (15%) while mean relative cover of shrubs (all native) was numerically similar for the three years (2%). However, the majority of forb cover in the grass-seeded treatment was contributed by non-native forb species (primarily 55%, 26%, and 11%) (Appendix 2, 3 and 4). In addition, I compared the grass treatment with the control treatment in the total forbs and shrub. The analysis showed that there are no significant differences between the two treatments (p= 0.45).

Also, forb, grass and shrub density was measured in 2013 for the seeded species. The total combined seeded forb and shrub density in the grass only treatment was predicted to be zero. No seeded forbs and shrubs were found in 2013 in the total of 56 frames (Appendix 5).

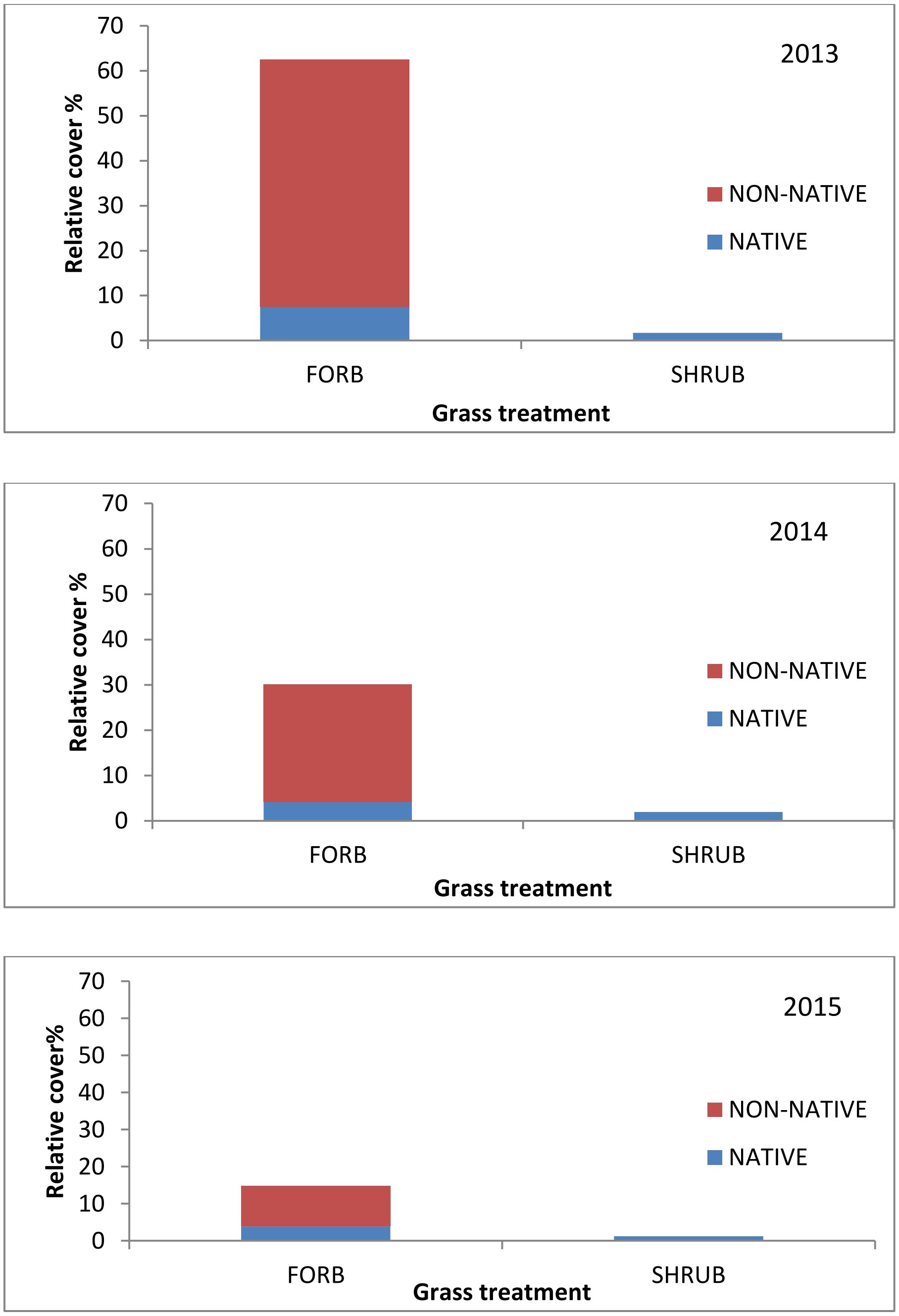

Figure 6: Mean relative cover (%) of forbs and shrubs in plots seeded with only grass species for 2013, 2014, and 2015. Red color presents the non-native species and the blue color presents the native species.

Hypothesis 3: Artificial perches will increase the abundance of native forbs and shrubs in plots sown only with grasses

This analysis compared grass-seeded plots versus grass-seeded plots with perches. I found no statistical differences in the mean relative cover for native forbs plus shrubs in the three years (P=0.186 in 2013, p= 0.238 in 2014, and p= 0.225 in 2015) (Figure 7).

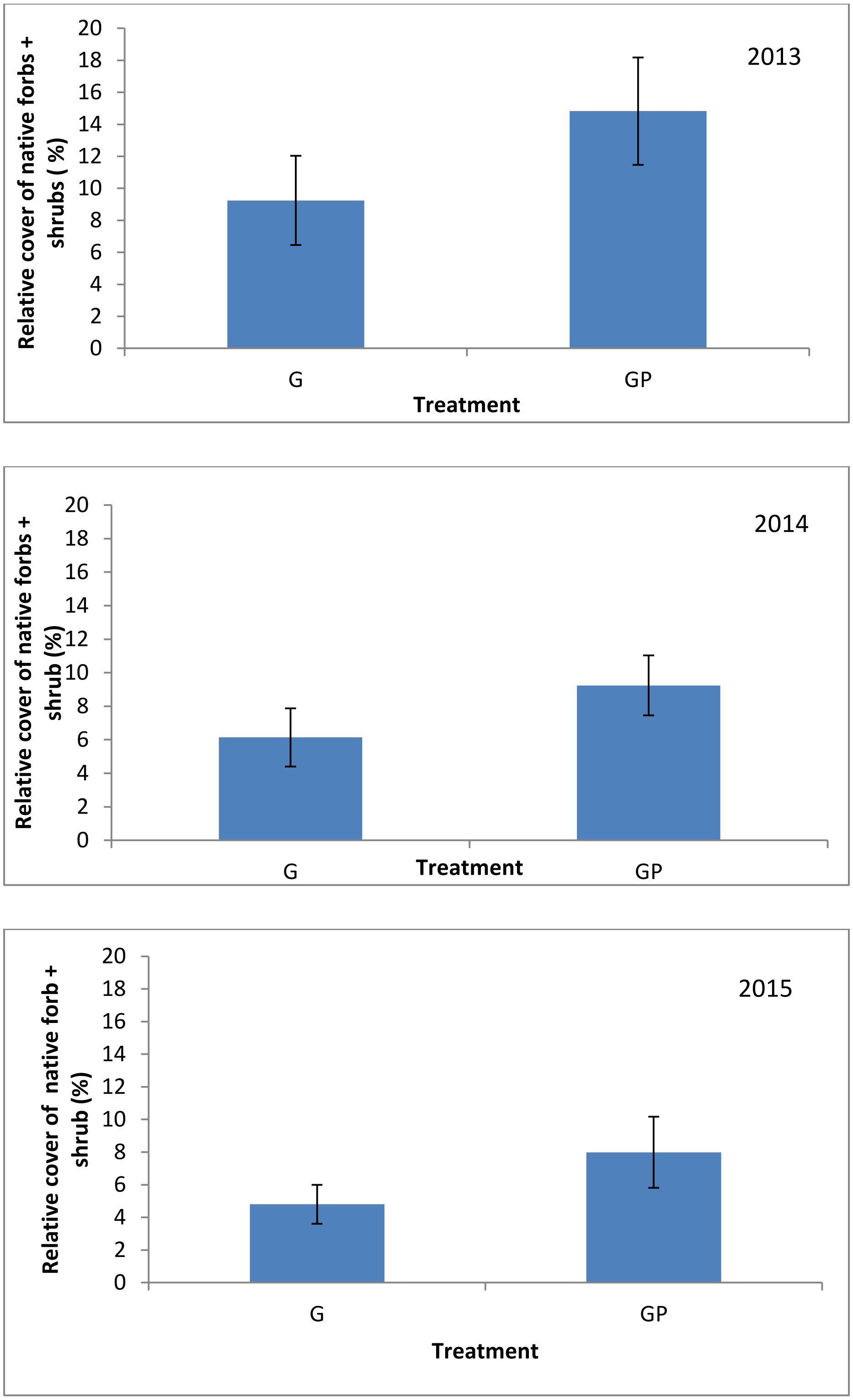

Figure 7: Mean and standard error (%) of relative cover of the total combined native forbs and shrubs in grass treatment (G) and grass with perches (GP) treatment for 2013, 2014, and 2015.

Discussion

In this study, seeded native plants from southern seed source produced more cover relative to species with northern seed source during the first three years after seeding (2013, 2014, and 2015). These findings led me to accept the first hypothesis that predicted southern native plant species would have better germination than northern species.

In this study, I planted southern species, a majority of which germinated and few of which did not. *Elymus Canadensis* (Canada wildrye), *Elymus trachycaulus* (Slender wheatgrass), *Cleome serrulata* (Rocky mountain beeplant), *Thelesperma filifolium* (Stiff greenthread) *,* *Machaeranthera tanacetifolia* (Tansyleaf tansy aster) and *Gutierrezia sarothrae* (Broom snakeweed) were the southern species that established. However, I saw that other species such as *Aristida purpurea* (Purple threeawn) had greater establishment which could be due to their previous existing populations. Evidence for this species that is already on the site came from the t-test result of the control plots. Many studies have shown that this species is adapted to high temperatures and has the ability to inhabit drier/ warmer environments (due to seed morphology and root physiology (Judd 1974; Fowler 1984; Kemp and Williams 1980; Berry and Bjorkman 1980).

Certain southern species did not become established at the site due to multiple species specific establishment barriers. One example of this is *Acacia greggii* (Catclaw acacia) which needs scarification to germinate (Gaddis, 2014), therefore its establishment may have been inhibited. Another example is Honey mesquite (*Prosopis glandulosa* Torr.), the seeds of which need to be consumed by some animals to get scarified in the digestive tract to improve their germinability (Brown and Archer 1987).

The establishment of some species is dependent on the ecosystem and dispersal type. Factors affecting seed germination and early seedling growth are often the primary determinants of the distribution of adult plants (De Jong and Klinkhamer 1988, Mustart and Cowling 1993). Soil moisture is a key limiting factor to seedling establishment in the semi-arid rangelands (Skoglund 1992, Snyman 1998, Schellenberg 1999). However, I did not consider these germination barriers in my experimental design.

I predicted that plots seeded only with grasses would not have any forb or shrub establishment. Interestingly, forb and shrub species were present in grass-only treatments during the study years (2013-2015). Therefore, I reject the second hypotheses of this study. One of the primary reasons that restoration professionals seed only native grasses in semi-arid ecosystem is that grasses are more competitive, establish faster and are more resilient at low resources levels (e.g. soil water and nutrients) than other life forms such as (forbs and shrubs) (Holubec 2005). The results from my study did not support my hypotheses that seeding grass will reduce forb and shrub germination in the site. Plant community restoration has recently focused on implementing the biodiversity-ecosystem perspective (Naeem 2006). In the past, ecologists have focused their studies on the relationship between biodiversity and ecosystem functioning (e.g. biogeochemical processes such as primary production). Since they found a positive relationship between biodiversity and ecosystem functions, their perceptive was shifted to look at the relationship between organisms that contribute to biodiversity across trophic groups (producers, herbivores, and predators).

Forbs and shrubs detected in grass-only treatments have likely: (1) germinated from the seed bank (seeds that dropped from previous vegetation at the site and persisted in the soil for long time because they are unable to germinate in a specified period of time under extreme environmental conditions.) and / or (2) were dispersed from nearby areas. Many burial experiments have shown that the seeds of many plant species have the ability to maintain long-term viability in the soil (seed dormancy) (Uhl and Clark 1983, Perez-Nasser and Vázquez-Yanes 1986, Hopkins and Graham 1987, Murray 1988).

Results of shrub and forb cover during 2013-2015 showed that forbs had higher cover compared to shrubs in the grass- only treatment and most of this forb cover was attributed to non-native forbs. Many studies have confirmed that numerous non-native forbs in temperate habitats produce long-lived seeds that persist in the soil for long periods and germinate when ideal climate conditions occur (Stieperaere and Timmerman 1983; Milberg 1992). For example, Sweetclover (*Melilotis officinalis*) a non-native forb species, was present in grass-only treatments for the years of my study (2013, 2014, and 2015) and with high mean cover in 2014 of 14%. According to (Mohammad et al. 1991), this plant is native to Europe and Asia and is now extensively distributed in North America where it colonizes regions of limited rainfall because it out-competes native plants for soil moisture.

My study found no evidence of increased native forbs or shrubs in plots with artificial perches. This result did not support my expectation that bird perches would increase seed dispersal and seedling establishment. Previous studies have shown that artificial perches encouraged seed dispersal into disturbed temperate ecosystems (McDonnell and Stiles 1983; McDonnell 1986; McClanahan and Wolfe 1987, 1993; Press 1996) and that artificial perches may be the most effective way to encourage bird visitors (Holl 1998).

The lack of a perch effect in my study could be due to the following reasons: (1) the type of perches that were used to attract the birds may not have been appropriate for grassland birds; (2) bird visitors may not have been common at this site; (3) seeds dispersed by birds in the plots may not have become established during the short duration of this study. McDonnell and Stiles (1983) suggested that vegetation branch perches would be a successful method for increased seed rain compared to simpler perches like I used in my study, because bird diversity was expected to be correlated with structural diversity of vegetation (Karr 1968). Seeds that might have been dropped by birds in my study may not have survived due to: predation by insects or other animals (Janzen 1971); lack of soil nutrients (Uhl 1987; Nepstad et al. 1991; Aide and Cavelier 1994) and competition with aggressive existing vegetation on the site.

Conclusion

Restoring more diverse plant communities to crested wheatgrass dominated areas have been proposed. I applied mixtures of native plant species consisting of southern or northern ecotypes to test if southern seed sources produced more cover than northern seed sources. I also examined the ability of native shrubs and forbs to colonize in areas seeded only with grasses, and the impact of artificial bird perches for recruitment of native plant diversity to accelerate the recovery of wildlife habitat. This study suggested that southern seed sources were better than northern seed sources and seeding grass- only had no effect on Forbs and shrubs to establish in grass-only treatments. Also, promoting seed dispersal via bird perches had no effect on forb and shrub cover.

Chapter 2

Relationships between plant diversity and insect diversity in restored plant communities

Introduction

Insects are a critically important component of most terrestrial ecosystems. Aboveground insects interact with leaves, stems and flowers and belowground insects interact with roots (Wardle, 2002). Insects maintain plant community productivity (Ashman et al.2004; Aguilar et al.2006) and play a vital role in biogeochemical cycling of soil nutrients (Myers 1996) via their feeding and burrowing activities (Price 1997). Details on interactions between plants and insects have been reviewed by Bezemer and Dam (2005). However, we are still missing more details on the importance of insects for plants.

The most important relationships between plants and insects are via herbivory and pollination (Blumenthal and Augustine 2009). Insects as pollinators play an essential role in wild plant community diversity. Many plants and insects have co-evolved forming close relationships. For example, many adult insects are excellent pollinators because most of their life is spent collecting pollen and nectar, which is a source of protein that they feed to their developing offspring and to survive and reproduce (Black et al.2011; Havens and Vitt 2016). Plants are dominant producers in many terrestrial ecosystems, but many plants cannot reproduce without insect intermediaries to carry pollen from flower to flower (Paton and Turner, 1985). However, the relationship between plant diversity and insects in rangeland ecosystems has not been studied extensively.

Mutualist interactions between plants and pollinators suggest that a decline in one group can result in a decline in the other (Aizen et al. 2012; Haddad et al. 2009). Such a decline has been seen in butterfly populations worldwide, as a result of declines in host plant availability (Warren 1985; Robertson et al. 1996). Many studies show that pollinator populations require diverse flowering plant populations (Black et al.2011). Declines in insect populations can be remediated by increasing plant community diversity in rangeland ecosystems. A study by Rowe and Holland (2013) suggested that restoring land with high plant species diversity supports insect food webs.

My objective in this study was to determine if restoration of plant diversity in rangeland plant communities can increase insect diversity. In my study, I quantified pollinating and browsing insects including bees, moths, wasps, ants, butterflies, flies, and beetles in experimentally restored rangeland plant communities to determine if increased plant species diversity positively affected insect abundance. My overall hypotheses were that insect diversity and abundance would be positively correlated with plant species diversity.

Specific Hypothesis

H1: The diversity and abundance of leafhoppers (Homoptera), ants (Hymenoptera: Formicidae), and beetles (Coleoptera) will be greater in plots seeded with grasses, forbs and shrubs (GFS) relative to plots seeded only with grass (G) or grasses plus forbs (GF).

H2: The diversity and abundance of Hymenoptera: Formicidae and Coleoptera species collected by pitfall traps will be greater in GFS plots relative to G and GF plots.

H3: Dipteral and Lepidoptera diversity and abundance will be greatest in the GFS treatment, intermediate in GF treatment and lowest in G treatments.

Material and Methods

Three replicated treatments were selected from an existing vegetation restoration study north of Fort Collins, Colorado, in Larimer County (UTM 40.707 N, 105.108 W) to test these hypotheses. Plots (13.9 x 30 m each) were sown with grass only (G), grasses and forbs (GF), or grasses, forbs, and shrubs (GFS). Seed mixes consisted of 29 grass species (G, GF, GFS treatments), 28 forb species (GF and GFS treatments), and 22 shrub species (GFS treatment) (refer to Tables 2, 3, 4 in chapter one of this thesis). Seven replicates of the G and GFS treatments and six replicates of the GF treatment were sampled (there was not enough butterfly sampling equipment for the 7th plot). Insects were sampled in August 2015 using three collecting methods aimed at sampling different portions of the insect community: drop-traps (canopy-dwelling insects), pitfall traps (primarily grounded-dwelling insects), and butterfly traps (pollinators).

Drop-trap

A leaf vacuum (Black and Decker, LSWV36) and a drop-trap that covered 0.25 m^2 of ground surface were used to collect invertebrates following methods described by Jonas and co-workers (2002). The drop-trap was made by firmly affixing mesh window screen to the top half of a 32-L plastic waste receptacle (Figure 1). The mesh was cone-shaped and had a hole in the middle to accommodate the leaf vacuum tube. A bag made of nylon stocking lined the inside of the vacuum tube and was used to collect insects suctioned from the plant canopy within the drop-trap.

Two samples (A and B) were collected in each plot at approximately 12.5 and 17.5 m north and south of the long axis of the plot, respectively. Each sample was collected by two people carrying the drop-trap and entering the plot from the downwind side. At each sample location, the trap was quickly dropped over the canopy and firmly held against the soil surface to prevent insect escape. Vegetation inside the drop-trap was vacuumed starting at the top of the canopy and working down to the ground. After making sure no insects were visible inside the trap, the intake tube was quickly removed from the trap and the nylon bag was taken off the intake tube. The bag was held closed until the contents of the sample were inverted into zippered plastic bag. Each bag was placed on ice in the field and placed in a freezer immediately upon returning to the lab.

Figure 8. Drop-trap used to vacuum-collect insects constructed from a trash can (121.13 Liters) and mesh window screen.

Setting Pitfall Traps

Three holes were dug along the centerline of the long axis of each plot at 10, 15, and 20-m (Figure 2); holes were made just large enough to accommodate a 950-ml plastic container. Traps were set by placing approximately 400 ml of biodegradable antifreeze that is non-toxic to humans and wildlife (RV & MARINE -50°F, SPLASH® RV & Marine Antifreeze) in each container. A funnel was placed on the top of each container to prevent small mammals from falling in or insects climbing out of the pitfall traps. Soil was packed firmly around each container so the surface was even with the top of the cup. Pitfall traps were retrieved after approximately 72 hours.

Pollinator Pan Traps

Pan traps were constructed by affixing four plastic bowls of different colors (blue, red, white and yellow) to wood platforms (Kearns and Inouye 1993). Each sampling plot had one pan trap platform placed along the centerline at 17.5 m of the long-axis of the plot (Figure 9). Bowls were filled with approximately 250 ml of water and 2-3 drops of Dawn dish detergent to break surface tension and more effectively trap visiting pollinators (Kearns and Inouye 1993). Pan traps were set for approximately 24 hours before samples were retrieved and returned to the lab.

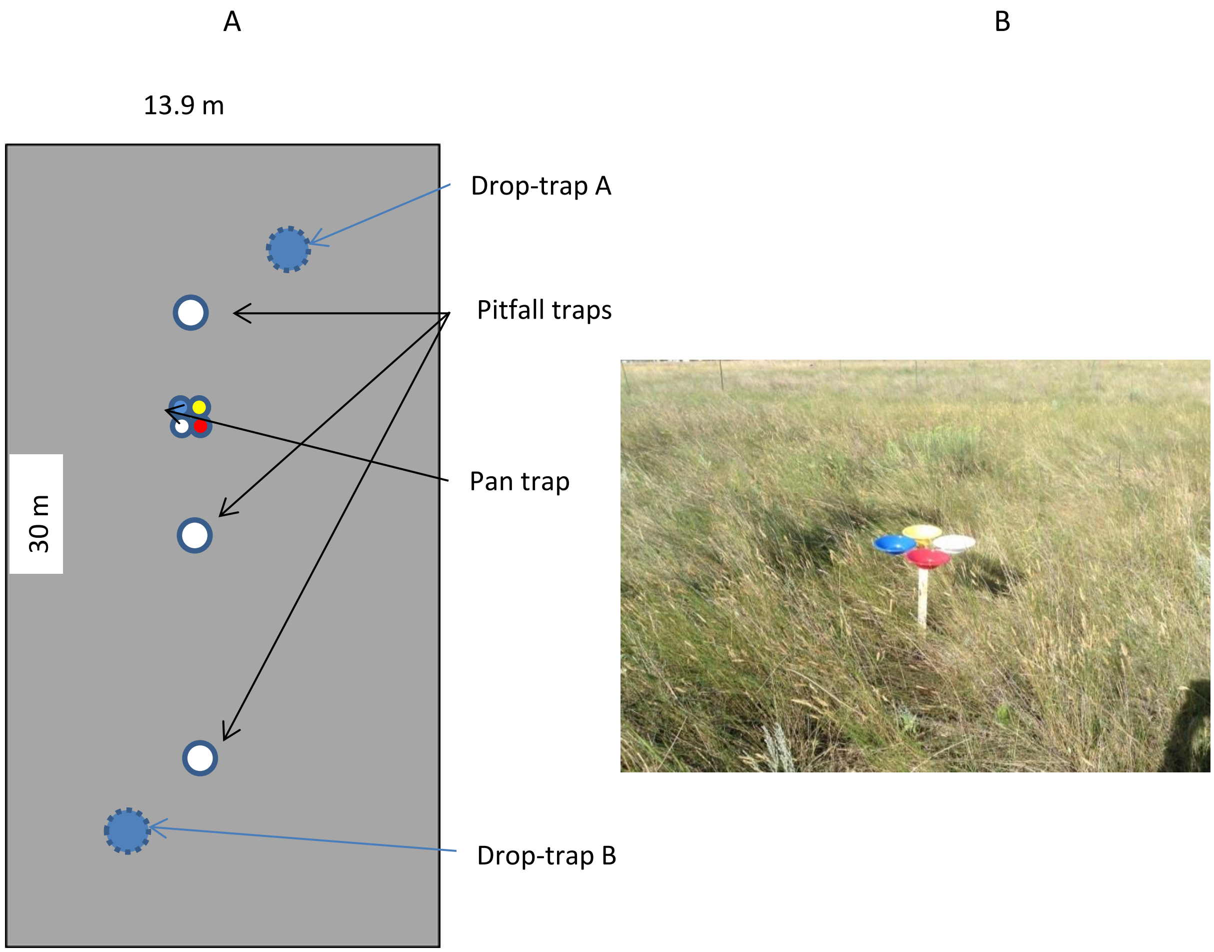

Figure 9. (A): Arrangement of insect sampling traps placed in each replicated plot seeded with diverse seed mixtures containing either grasses (n=7), grasses plus forbs (n=6), or grasses with forbs and shrubs (n=7). (B): Pan traps constructed from wood stands supporting four different colored bowls (blue, red, white, and yellow) placed in the field to collect pollinator insects.

Data Collection

All insects were counted and identified to order (or family, in the case of ants) according to Borror et al. (1992). Drop-trap counts were converted to density based on the surface area sampled; all other abundance data presented are based on raw number of individuals collected in each plot.

Statistical Analysis

Using total insect data from 20 plots that were seeded with different plant life forms (grass, grass with forb, and grass with forb and shrub), insect order richness and plant species richness (plant data from 2015) were calculated in each plot for each collection method (drop-trap, pitfall trap and pan trap). I used scatter plots to test whether total observed insect richness increased with increasing number of plant species (if the relationship between insect and plant richness was liner or not). Insect data were analyzed using analysis of variance in SAS 9.3 version (SAS Institute INC, Cary, NC, USA, 2011) to examine the effect of the treatments on density (drop-traps) or abundance (pitfall traps, pan traps), and frequency of occurrence (drop-traps, pitfall traps) and insect groups (Homoptera, Hymenoptera (ants), Coleoptera, Lepidoptera and Diptera). Values were transformed to satisfy the normality assumption by using square root or log+1 transformation. When transformations were inadequate to meet the normality assumption, nonparametric tests (Wilcoxon test) were used. A binomial test was performed on the data to determine if insects were present or absent in the treatments when insect population data did not meet the normal distribution assumption for analysis of variance. For all tests, $\alpha = 0.05$.

Results

In total, there were 52 individuals from 7 orders collected in drop-traps, 1610 individuals from 9 orders collected in pitfall traps and 1019 individuals from 10 orders collected in pan traps. I did not find a positive relationship between plant diversity and total insect diversity. The scatter plot showed non-liner relationship between plant richness and insect richness (Figure 10).

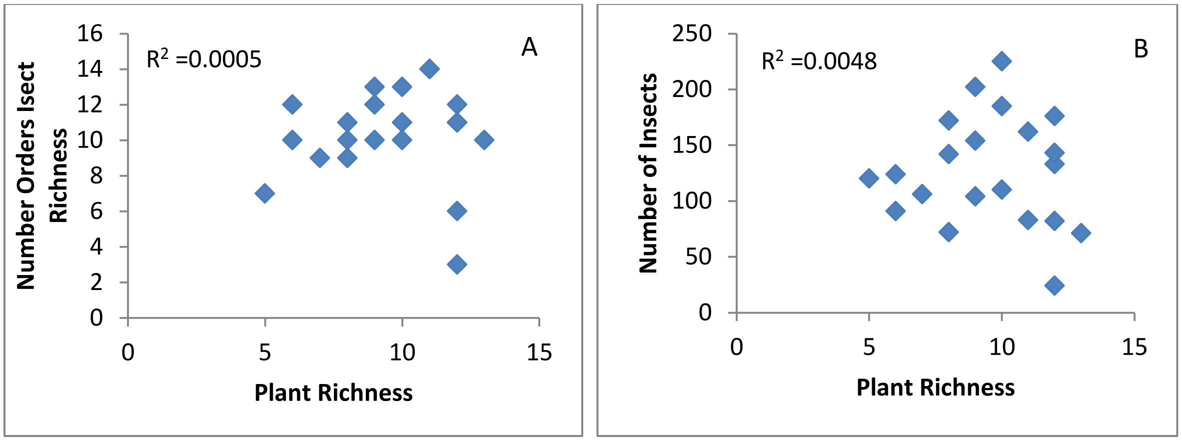

Figure 10. Relationship between total plant richness and insect order richness (A) and between total plant richness and insect abundance (B).

Additional analyses of the insect data were done to test the sub-hypotheses. For H1, I compared treatments (G, GF, and GFS) for the presence of the following orders: Homoptera, Hymenoptera and Coleopteran in drop trap samples. Sampling data did not meet the normal distribution assumption for analysis of variance due to many zeros in the data. Binomial test was applied to the data and the results showed statistical differences between only two treatments (GF and GFS) in the Homoptera group (p= 0.03) (Figure 11).

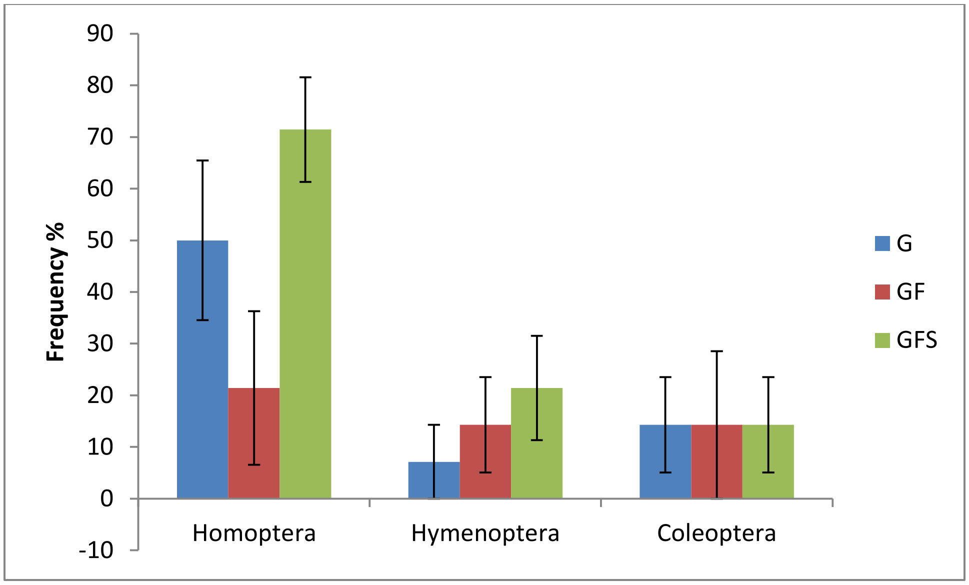

Figure 11. Frequency mean and stander error (%) of Homoptera, Hymenoptera and Coleoptera insect orders from drop-trap samples in plots seeded with grass (G), grass plus forbs (GF) or grass plus forbs and shrubs (GFS).

For H2, I compared the abundance of Hymenoptera, Formicidae and Coleoptera in the various treatment plots using data collected by pitfall traps. Abundance of Hymenoptera, Formicidae (log+1 transformed) per plot for each treatment was calculated. The statistical results of the abundance of Formicidae (ants) showed no differences across the three treatments. A non-parametric test (Wilcoxon) was done on abundance of Coleoptera (beetles) and no statistical differences were found across treatments. Frequency of Coleoptera (untransformed) per plot for each treatment was calculated. Coleoptera species were present in each pitfall trap. So, statistical analysis was not done on frequency of Coleoptera. The average abundance of Hymenoptera: Formicidae and Coleoptera species per plot revealed no differences across treatments (Figure 12). Also, the total abundance of all insects did not differ significantly across treatments.

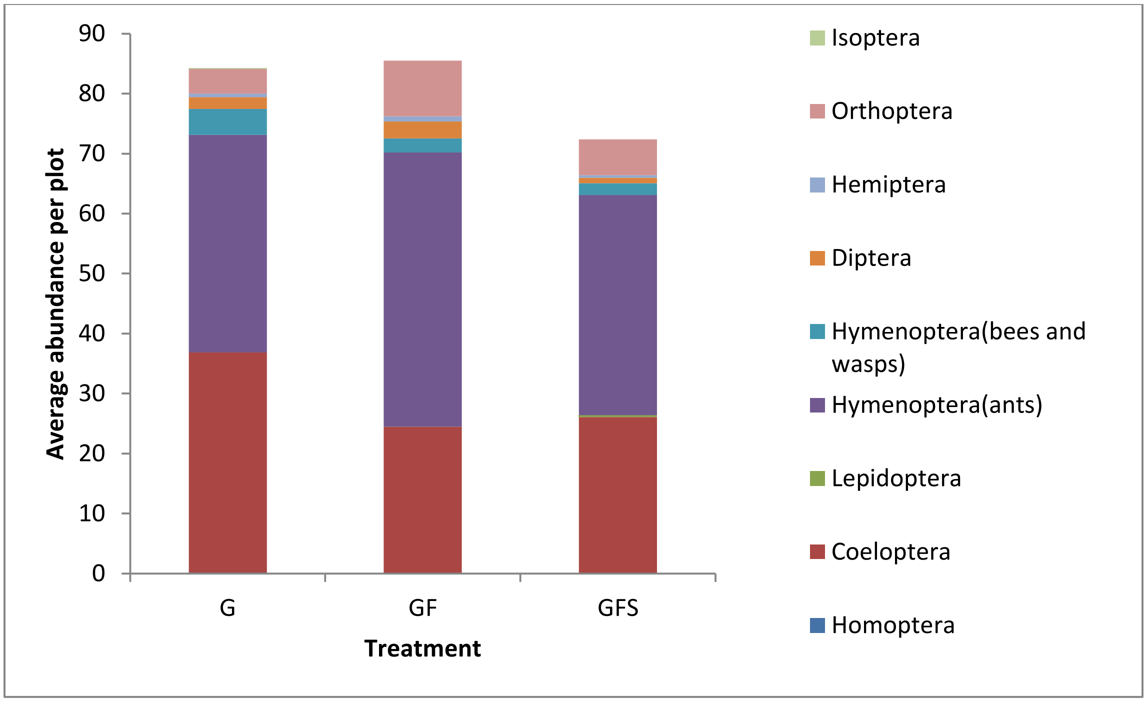

Figure 12. Mean abundance of Coleoptera, Diptera, Hemiptera, Hymenoptera (ants), Formicidae, Hymenoptera (bees and wasps), Isoptera and Orthoptera individuals per plot for grass (G), grass with forb (GF) and grass with forb with shrub (GFS) treatments from pitfall-trap technique data.

Finally, for H3, Diptera and Lepidoptera abundance from pan trap data did not differ across treatments (Figure 13).

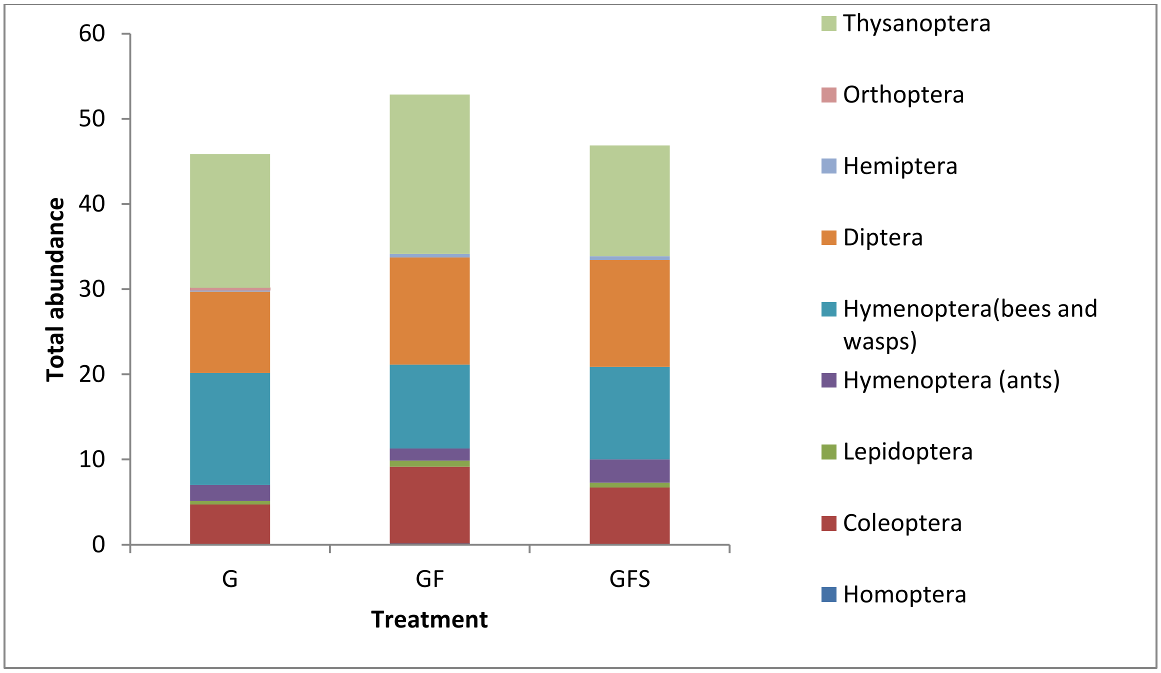

Figure 13. Total abundance of Coleoptera, Diptera, Hemiptera, Hymenoptera (ants), Formicidae, Hymenoptera (bees and wasps), Orthoptera and Thysanoptera individuals per plot for grass (G), grass with forb (GF) and grass with forb with shrub (GFS) treatments from pan-trap technique data.

Discussion

High diversity of plant species is thought to increase insect richness (Rowe and Holland 2013). Areas with greater plant production also support more insects (Srivastava and Lawton, 1998; Hurlbert, 2004). In this study, different techniques were used to collect insect data and test the relationship between plant species richness and insect richness. I predicted high richness of insects in plots seeded with diverse seed mixes (grasses, forbs, and shrubs) relative to less diverse seed mixes (grasses only). My results did not support my overall hypothesis. However, other studies have shown plant species diversity increases insect species diversity. For example, (Siemann et al 1989) found a significant positive relationship between insect species richness and plant functional group richness. However, Symstad and Haarstad (2000) found that arthropod order richness was unrelated to plant functional richness in a grassland system.

The order Homoptera was the most abundant group found in the GFS treatment (*n*=15) from drop-trap data. Many previous studies showed that Homoptera species distribution largely depends on the presence of specific host plant species (Biedermann, 2002). In terms of generalist and specialist insects, most Homoptera species are specialist and they select certain plant species or functional types of plants (Augustine and McNughton, 1998). A study of leafhoppers species (Homoptera) showed that leafhopper species feed on specific plant functional types of grasses and forbs (Biedermann et al. 2005; Trivellone et al. 2012); therefore, there may be higher leafhopper diversity in areas with high plant functional group diversity. My study found many forbs and grass species in GFS treatment plots (Appendix 4, first chapter). This suggests that Homoptera species increase with greater diversity of resources and with different plant life forms and different functional groups.

Generally, results from my study varied from my expectations. Total insect richness did not differ among treatments (G, GF and GFS). First, I thought that plant species that I sampled (the rate is 5-13 as in figure 10) were not enough to get a significant results for the relationship between plant richness and insect richness, but when I looked to another study (Haddad et al 2001), I found that they got a significant positive relationship between plant richness and insect richness by little bit high rate of plants species. The overall reason that I did not find significant differences could be the season of data collection and lack of repeated sampling. The insect data for this study were collected once in 2015 and during one season (August, dry season), therefore, the insect richness observed only reflects the dry period in one month of the year.

Total precipitation in August, 2015 only represented 4% of the rain observed for the year (refer to table 1 in previous chapter). However, the amount of rain for August 2015 was the highest seen in August for the past three years. Therefore, these data do not represent the climate variability seen seasonally and annually. A study by Wenninger and Inouye (2007) showed that insect richness was influenced indirectly by other factors such as seasonal change. In their study, they added irrigation to their treatments and found a correlation between high insect richness and plant diversity in treatments that were irrigated. This study also showed that the data collected in August was not a good representation of the data collected throughout the growing season due to low precipitation and soil moisture (these two factors are an important for insect growth). Another reason why my data may not support my hypothesis could be due to my methodology. Although, many researchers have used same capture techniques that I did in this study (drop-trap, Jonas et al. 2002, pitfall trap, Lovei and Sunderland 1996, and pan trap, Joshua et al 2007), insect movement was difficult to track in my study. It is possible that the observed insects were sensitive to capture techniques. Wind could have influenced the stability of the pan traps, leading to a loss of my sample before data collection. Another limitation of this experiment was that the sampling areas were small compared to other insect studies. Most other studies analyzed insect diversity using large experimental area (Haddad et al. 2001). My hypotheses have been previously supported in other studies and could have been supported with a different experimental design.

Conclusion

The overall hypothesis that I tested looked at the dependency of insect diversity on plant species diversity. In my experiment, plant-insect diversity relationships were not significant; however, the Homoptera group showed higher abundances in high plant diversity plots compared to low plant diversity plots. Nonetheless, this result could be supported in future studies that investigate the relationship between plant and insect species diversity.

Plant Seeding Method

Appendix 1. Seeding method and seed source for seeded species.

Common name	Genus	Species	Seeding method	Source state
Grass				
Purple threeawn	*Aristida*	*pupurea*	Broadcast	AZ
Sand bluestem	*Andropogon*	*hallii*	Broadcast	KS
Big bluestem	*Andropogon*	*gerardii*	Broadcast	CA
Cane bluestem	*Bothriochloa*	*barbinodis*	Broadcast	AZ
Sideoats grama	*Bouteloua*	*curtipendula*	Broadcast	MN
Blue grama	*Bouteloua*	*gracilis*	Broadcast	CA
Galleta	*Pleuraphis*	*jamesii*	Broadcast	TX
Little bluestem	*Schizachyrium*	*scoparium*	Broadcast	MN
Buffalograss	*Bouteloua*	*dactyloides*	Broadcast	TX
Prairie sandreed	*Calamovilfa*	*longifolia*	Broadcast	MT
Canada wildrye	*Elymus*	*canadensis*	Drill	CA
Squirreltail	*Elymus*	*elymoides*	Drill	WA
Thickspike wheatgrass	*Elymus*	*lanceolatus*	Drill	OR
Slender wheatgrass	*Elymus*	*trachycaulus*	Drill	CA
Needle and thread	*Hesperostipa*	*comata*	Drill	WY
Prairie Junegrass	*Koeleria*	*macrantha*	Drill	WA
Green needlegrass	*Nassella*	*viridula*	Drill	MT
Wastern wheatgrass	*Pascopyrum*	*smithii*	Drill	MT
Sandberg bluegrass	*Poa*	*secunda*	Drill	WA
Bluebunch wheatgrass	*Pseudoroegneria*	*spicata*	Drill	CA
Sixweeks fescue	*Vulpia*	*octoflora*	Drill	CA
Indian ricegrass	*Achnatherum*	*hymenoides*	Drill	MT
Saltgrass	*Distichlis*	*spicata*	Drill	UT
Plains lovegrass	*Eragrostis*	*intermedia*	Drill	AZ
Scratchgrass	*Muhlenbergia*	*asperifolia*	Drill	NV
Switchgrass	*Panicum*	*virgatum*	Drill	MN
Large-spiked plains bristlegrass	*Setaria*	*macrostachya*	Broadcast	TX
Alkali sacaton	*Sporobolus*	*airoides*	Broadcast	KS
Sand dropseed	*Sporobolus*	*cryptandrus*	Broadcast	CO
Forb				
Blanketflower	*Gaillardia*	*aristata*	Broadcast	IN
Hairy false goldenaster	*Heterotheca*	*villosa*	Broadcast	CO
Dotted blazing star	*Liatris*	*punctata*	Broadcast	CO
Plains zinnia	*Zinnia*	*grandiflora*	Broadcast	AZ
Tarragon	*Artemisia*	*dracunculus*	Broadcast	CA

Textile onion	*Allium*	*textile*	Drill	WY
Drummond's milkvetch	*Astragalus*	*drummondii*	Drill	CO
Rocky Mountain beeplant	*Cleome*	*serrulata*	Drill	WY
Black samson	*Echinacea*	*angustifolia*	Drill	SD
Utah sweetvetch	*Hedysarum*	*boreale*	Drill	CO
Common sunflower	*Helianthus*	*annuus*	Drill	CO
Silvery lupine	*Lupinus*	*argenteus*	Drill	NV
Pennsylvania smartweed	*Polygonum*	*pensylvanicum*	Drill	NE
Fendler's meadow-rue	*Thalictrum*	*fendleri*	Drill	UT
Stiff greenthread	*Thelesperma*	*filifolium*	Drill	TX
Crested pricklypoppy	*Argemone*	*polyanthemos*	Broadcast	ME
Lambsquarters	*Chenopodium*	*album*	Broadcast	NE
White prairie clover	*Dalea*	*candida*	Broadcast	MN
Purple prairie clover	*Dalea*	*purpurea*	Broadcast	MN
Sanddune wallflower	*Erysimum*	*capitatum*	Broadcast	CO
Tansyleaf tansy aster	*Machaeranther*	*tanacetifolius*	Broadcast	CA
Tufted evening primrose	*Oenothera*	*caespitosa*	Broadcast	UT
Purple locoweed	*Oxytropis*	*lambertii*	Broadcast	AZ
Broadbeard beardtongue	*Penstemon*	*angustifolius*	Broadcast	WY
Upright prairie coneflower	*Ratibida*	*columnifera*	Broadcast	WA
Scarlet globemallow	*Sphaeralcea*	*coccinea*	Broadcast	UT
Prairie spiderwort	*Tradescantia*	*occidentalis*	Broadcast	CO
Hoary verbena	*Verbena*	*stricta*	Broadcast	NE
Shrub			Broadcast	
Yellow rabbitbrush	*Chrysothamnus*	*viscidiflorus*	Broadcast	NV
Rubber rabbitbrush	*Ericameria*	*nauseosa*	Broadcast	UT
Winterfat	*Krascheninnikovia*	*lanata*	Broadcast	NM
Greasewood	*Sarcobatus*	*vermiculatus*	Broadcast	UT
Prairie sagewort	*Artemisia*	*frigida*	Hand	MT
White sagebrush	*Artemisia*	*ludoviciana*	Hand	WY
Wyoming big sagebrush	*Artemisia*	*tridentata*	Hand	UT
Saskatoon serviceberry	*Amelanchier*	*alnifolia*	Drill	UT
Utah serviceberry	*Amelanchier*	*utahensis*	Drill	CO
Fourwing saltbush	*Atriplex*	*canescens*	Drill	UT
Gardner's saltbush	*Atriplex*	*gardneri*	Drill	WY
Alderleaf mountain mahogany	*Cercocarpus*	*montanus*	Drill	CO
Chokecherry	*Prunus*	*virginiana*	Drill	MT
Bitterbrush	*Purshia*	*tridentata*	Drill	UT
Skunkbush sumac	*Rhus*	*trilobata*	Drill	UT
Catclaw acacia	*Acacia*	*greggii*	Hand	ME
Honey mesquite	*Prosopis*	*glandulosa*	Hand	CA
Soapweed yucca	*Yucca*	*glauca*	Hand	CO

Sand sagebrush	*Artemisia*	*filifolia*	Broadcast	UT
Broom snakeweed	*Gutierrezia*	*sarothrae*	Broadcast	AZ
Golden currant	*Ribes*	*aureum*	Broadcast	UT
Wax currant	*Ribes*	*cereum*	Broadcast	UT

PLANT RELATIVE COVER DATA

Appendix2. Mean relative cover (MEAN± SE %) of each species collected in 2013. Six treatments were applied to the site: grass (G), grass forb (GF), grass forb shrub (GFS), grass perches (GP), grass shrub (GS), and unseeded (U).Treatments were applied in randomized complete design. Species were not present where values are missing.

	Seeded	Nativity to North America	TREATMENTS					
			G	GF	GFS	GP	GS	CONTROL
FORB								
Astragalus drummondii	x	x						
Bassia scoparia			1.31 (0.91)	0.71 (0,71)	1.21 (0.57)	3.17 (1.09)	0.74 (0.49)	
Brazoria arenaria		x				0.73 (0.47)		
Carduus nutans			0.31 (0.31)					0.63 (0.63)
Chenopodium album	x	x		0.71 (0.71)				
Chamaesyce maculate		x	2.52 (1.42)	0.82 (0.82)		0.31 (0.31)	1.38 (0.68)	5.38 (2.95)
Cirsium undulatum		x					0.53 (0.53)	
Cleome serrulata	x	x	0.39 (0.39)	2.42 (0.89)	6.06 (2.51)	0.60 (0.60)		
Convolvulus arvensis			44.9 (10.1)	18.8 (4.92)	18.4 (2.93)	31.8 (4.55)	54.1 (5.57)	37.7 (6.86)
Gaillardia aristata	x	x		0.39 (0.39)				
Gaura coccinea		x		0.58 (0.58)	0.79 (0.51)	1.29 (0.83)	1.38 (1.05)	1.11 (0.72)
Helianthus annuus	x	x	1.21 (0.82)	39.3 (4.22)	36.1 (4.90)	1.21 (0.60)	1.18 (0.85)	2.72 (1.78)
Heterotheca villosa	x	x	0.43 (0.43)		0.39 (0.39)			
Lappula occidentalis		x		0.45 (0.45)				
Linaria dalmatica				0.45 (0.45)				

Lygodesmia juncea		x		0.41 (0.41)				
Machaeranthera tanacetifolia	x	x		0.77(0.77)	0.49 (0.49)			
Melilotis officinalis			6.26 (2.32)	1.09 (0.52)	4.06 (1.53)	6.08 (1.93)	6.10 (1.66)	7.91 (1.94)
Picradeniopsis oppositifolia		x			0.79 (0.51)	0.93 (0.93)	0.32 (0.32)	1.93 (1.06)
Salsola tragus			2.29 (1.51)		1.62 (1.08)	1.83 (0.73)	2.99 (1.48)	2.61 (1.07)
Solanum triflorum		x	1.58 (0.58)	0.45 (0.45)	0.36 (0.36)	1.60 (0.62)	2.72 (1.04)	1.93 (1.37)
Sphaeralcea coccinea	x	x	0.45 (0.45)					
Symphyotrichum ericoides		x	0.55 (0.55)	3.72 (1.98)	1.52 (0.80)	4.36 (2.29)	3.64 (1.12)	2.96 (1.73)
Solawum rostratum		x			0.36 (0.36)		0.53 (0.53)	
Thelesperma filifolium	x	x		1.03 (0.67)	0.32 (0.32)			
Quimcula lobate		x						0.51 (0.51)
GRASS								
Achnatherum hymenoides	x	x	0.83(0.54)	0.77(0.77)				
Agropyron cristatum			6.44 (2.44)	8.10 (3.46)	4.88 (2.22)	7.83 (2.61)	4.91 (1.66)	6.05 (1.45)
Aristida purpurea	x	x	22.8 (11.8)	16.47 (4.88)	13.19 (5.83)	13.64 (5.34)	9.92 (4.05)	18.87 (5.46)
Andropogon gerardii	x	x	0.77 (0.77)					
Bouteloua curtipendula	x	x	0.66 (0.43)	0.29 (0.29)		0.92 (0.44)	1.02 (0.71)	
Bouteloua gracilis	x	x	0.39 (0.39)			0.31 (0.31)		
Bromus inermis								0.30 (0.30)
Bromus japonicas			0.36 (0.36)				0.32 (0.32)	
Elymus Canadensis	x	x		0.71 (0.71)		1.23 (0.61)	0.68 (0.68)	
Elymus elymoides	x	x				1.14 (0.74)	0.53 (0.53)	
Elymus trachycaulus	x	x				1.38 (1.09)	0.53 (0.53)	
Elymus L					6.49 (5.35)	5.82 (5.82)	1.36 (1.36)	3.06 (3.06)
Hesperostipa comata	x	x				0.28 (0.28)		
Hirtella jamesii		x				0.33 (0.33)		
Muhlenbergia asperifolia	x	x				0.28 (0.28)		
Nassella viridula	x	x	0.39 (0.39)			2.32 (1.18)	0.83 (0.55)	

Pascopyrum smithii	x	x	1.46 (1.08)			1.28 (0.63)		
Panicum virgatum	x	x				0.31 (0.31)		
Pleuraphis jamesii	x	x				1.10 (0.80)	0.34 (0.34)	
Schizachyrium scoparium	x	x		0.68 (0.68)	0.43 (0.43)	2.01 (0.74)		
Sporobolus airoides	x	x	0.45 (0.45)1				0.68 (0.68)	
Sporobolus cryptandrus	x	x				0.60 (0.60)	0.34 (0.34)	0.73 (0.73)
UNK_1618			1.16 (0.78)			0.81 (0.56)	0.87 (0.58)	
Annual bindweed					0.87 (0.87)			2.55 (2.55)
SHRUB								
Artemisia ludoviciana	x	x			0.39 (0.39)			
Ericameria nauseosa	x	x	1.22 (0.83)	0.85 (0.55)	1.07 (0.74)	3.15 (1.19)	1.29 (0.62)	1.58 (0.89)
Gutierrezia sarothrae	x	x	0.48 (0.48)		0.36 (0.36)	1.10 (0.80)		1.19 (1.19)
Purshia tridentata	x	x					0.87 (0.58)	

Appendix 3. Mean relative cover (MEAN± SE %) of each species collected in 2014. Six treatments were applied to the site: grass (G), grass forb (GF), grass forb shrub (GFS), grass perches (GP), grass shrub (GS), and unseeded (U).Treatments were applied in a randomized complete design. Species were not present where values are missing.

	Seeded	Nativity to North America	TREATMENTS					
			G	GF	GFS	GP	GS	CONTROL
FORB								
Acroptilon repens							0.15 (0.15)	0.14 (0.14)
Ambrosia tomentosa		X			0.60 (0.60)			
Astragalus drummondii	X	X					0.16 (0.16)	
Camelina microcarpa			2.96 (1.91)		0.57 (0.57)	0.15 (0.15)	1.45 (0.81)	0.38 (0.38)
Cirsium undulatum		X		0.18 (0.18)				
Convolvulus arvensis			4.62 (2.20)	7.32 (0.92)	4.57 (0.96)	5.88 (1.72)	7.47 (1.21)	6.01 (2.16)
Coreopsis sp		X		0.76 (0.41)	1.36 (0.62)			
Descurainia pinnata		X					0.39 (0.25)	
Emily sp					0.20 (0.20)			
Gaillardia aristata	X	X		0.18 (0.18)				
Glandularia bipinnatifida		X						0.27 (0.27)
Grindelia squarrosa		X	0.44 (0.29)		0.30 (0.30)		0.13 (0.13)	
Helianthus annuus	X	X	0.18 (0.18)					
Heterotheca villosa	X	X	0.32 (0.32)		0.40 (0.40)	0.31 (0.31)	0.18 (0.18)	
Lappula occidentalis		X			0.16 (0.16)			
Lactuca serriola			3.59 (1.31)	2.57 (0.65)	4.30 (1.03)	2.51 (1.05)	7.74 (2.02)	5.39 (1.88)
Linaria dalmatica				0.69 (0.69)		0.40 (0.40)	0.45 (0.45)	0.23 (0.15)

Linum lewisii		x	0.34 (0.22)			0.37 (0.25)	0.13 (0.13)	
Machaeranthera tanacetifolia	x	x		0.18 (0.18)	0.75 (0.42)			0.15 (0.15)
Melilotis officinalis			14.3 (4.16)	4.32 (1.01)	8.06 (2.22)	8.01 (2.02)	7.61 (1.55)	14.5 (3.61)
Penstemon angustifolius	x	x		0.66 (0.39)	0.86 (0.37)			
Picradeniopsis oppositifolia		x	0.49 (0.34)	0.94 (0.58)	0.77 (0.52)	2.11 (1.24)	0.13 (0.13)	1.74 (0.67)
Ratibida columnifera	x	x		0.58 (0.29)	0.16 (0.16)			
Salsola tragus				0.26 (0.25)	0.48 (0.48)			0.53 (0.38)
Symphyotrichum ericoides		x	2.43 (1.03)	4.03 (0.90)	1.74 (0.78)	2.93 (1.08)	3.35 (0.80)	2.59 (0.91)
Synthyris reniformis		x			0.74 (0.74)			
Sisymbrium irio								0.27 (0.27)
Thelesperma filifolium	x	x		0.18 (0.18)	0.14 (0.14)	0.29 (0.29)		
Tragopogon dubius			0.46 (0.46)		0.55 (0.26)			0.30 (0.19)
Verbascum thapsus							0.22 (0.22)	
Physalis longifolia		x					0.18 (0.18)	
GRASS								
Achnatherum hymenoides	x	x	2.37 (0.71)	1.86 (1.12)	0.26 (0.26)	3.43 (0.85)	2.15 (0.60)	
Agropyron cristatum			38.6 (6.96)	60.7 (3.19)	55.4 (5.44)	41.9 (3.77)	53.2 (5.06)	52.1 (5.00)
Andropogon gerardii	x	x				0.14 (0.14)		
Aristida purpurea	x	x	24.5 (7.81)	8.58 (3.18)	8.57 (3.94)	9.82 (4.16)	6.60 (3.40)	10.6 (4.32)
Bouteloua curtipendula	x	x				0.40 (0.40)		
Bouteloua gracilis	x	x	0.15 (0.15)					
Bromus inermis								0.16 (0.16)
Bromus japonicus			0.20 (0.20)	0.89 (0.62)	0.18 (0.18)	1.22 (0.39)	0.13 (0.13)	
Bromus tectorum				0.30 (0.30)			0.76 (0.31)	
Elymus canadensis	x	x		0.55 (0.40)	0.44 (0.44)	3.03 (1.74)	0.39 (0.25)	
Elymus elymoides	x	x		1.11 (1.11)		1.98 (1.31)	0.40 (0.27)	
Elymus lanceolatus	x	x		0.28 (0.28)	0.13 (0.13)	0.75 (0.42)	2.06 (0.92)	0.22 (0.22)
Elymus trachycaulus	x	x				0.27 (0.18)		

Elymus sp		x	0.72 (0.72)	0.43 (0.29)	0.42 (0.42)	0.95 (0.74)	0.16 (0.16)	
Hesperostipa comata	x	x	0.66 (0.33)	0.61 (0.61)	0.76 (0.32)	4.40 (0.78)	1.74 (0.66)	0.15 (0.15)
Leymus cinereus		x	0.30 (0.30)		3.09 (2.80)	4.72 (4.72)	0.16 (0.16)	1.92 (1.92)
Melica altissima			0.47 (0.33)		0.64 (0.43)	0.37 (0.25)		
Pascopyrum smithii	x	x		0.15 (0.15)				
SHRUB								
Artemisia cana		x			0.45 (0.45)			
Artemisia frigida	x	x	0.30 (0.30)	0.22 (0.22)	1.12 (0.49)	0.18 (0.18)	0.88 (0.34)	0.22 (0.22)
Artemisia ludoviciana	x	x		0.11 (0.11)				
Atriplex canescens	x	x					0.13 (0.13)	
Ericameria nauseosa	x	x	1.29 (0.66)	0.97 (0.38)	0.76 (0.39)	2.70 (1.20)	0.93 (0.48)	1.12 (0.55)
Gutierrezia sarothrae	x	x	0.35 (0.23)	0.36 (0.36)	0.14 (0.14)			0.39 (0.39)
Purshia tridentata	x	x					0.26 (0.26)	
Salsola sp						0.36 (0.36)		
Sarcobatus vermiculatus					0.26 (0.26)			
Symphoricarpos albus		x			0.69 (0.44)	0.36 (0.36)		0.66 (0.66)

Appendix 4. Mean relative cover (MEAN± SE %) of each species collected in 2015. Six treatments were applied to the site: grass (G), grass forb (GF), grass forb shrub (GFS), grass perches (GP), grass shrub (GS), and unseeded (U).Treatments were applied in a randomized complete design. Species were not present where values are missing.

	Seeded	Nativity to North America	TREATMENTS					
			G	GF	GFS	GP	GS	CONTROL
FORB								
Argemone polyanthemos	x	x		0.14 (0.14)				
Astragalus drummondii	x	x		0.22 (0.22)	0.30 (0.19)		0.15 (0.15)	
Bassia scoparia			0.34 (0.22)		0.18 (0.18)			0.20 (0.20)
Cirsium undulatum		x	0.14 (0.14)	0.33 (0.21)		0.20 (0.20)	0.16 (0.16)	
Claytonia caroliniana		x				0.15 (0.15)		
Convolvulus arvensis			9.43 (2.49)	4.08 (1.41)	7.36 (1.30)	5.67 (1.42)	6.12 (1.56)	6.77 (1.34)
Cryptantha SP		x			0.14 (0.14)			
Elymus californicus		x	0.32 (0.32)			0.61 (0.33)		
Erysimum capitatum	x	x					0.14 (0.14)	1.06 (1.06)
Gaillardia aristata	x	x		0.15 (0.15)				
Gaura coccinea		x	0.18 (0.18)			0.15 (0.15)	0.14 (0.14)	
Grindelia squarrosa		x			0.14 (0.14)	0.51 (0.51)		0.16 (0.16)
Helianthus annuus	x	x			0.13 (0.13)			0.14 (0.14)
Heterotheca villosa	x	x		0.13 (0.13)		0.14 (0.14)	0.15 (0.15)	0.39 (0.39)
Lactuca serriola			0.70 (0.35)	0.14 (0.14)	0.29 (0.18)		0.45 (0.30)	0.15 (0.15)
Linaria dalmatica				0.91 (0.73)				
Liatris punctata		x	0.30 (0.30)					
Melilotis officinalis			0.16 (0.16)	0.15 (0.15)	1.93 (1.10)	1.19 (0.47)	0.91 (0.46)	0.47 (0.23)

Penstemon angustifolius	x	x		1.18 (0.68)	0.45 (0.21)		0.57 (0.57)	
Picradeniopsis oppositifolia		x	0.75 (0.61)	0.35 (0.35)	0.40 (0.20)	0.99 (0.99)		0.65 (0.36)
Ratibida columnifera	x	x			0.16 (0.16)			
Rudbeckia hirta		x		0.16 (0.16)	0.18 (0.18)			
Salsola tragus								0.22 (0.22)
Sphaeralcea coccinea	x	x						0.14 (0.14)
Symphyotrichum ericoides		x	2.37 (0.78)	3.66 (1.38)	3.49 (1.03)	2.63 (0.70)	3.42 (1.22)	1.54 (0.49)
Thelesperma filifolium	x	x		0.15 (0.15)	0.15 (0.15)			
GRASS								
Achnatherum hymenoides	x	x		0.18 (0.18)	0.15 (0.15)	0.82 (0.52)		
Agropyron cristatum			61.93 (5.03)	71.70 (1.36)	64.7 (5.01)	60.0 (3.73)	70.8 (3.49)	70.95 (3.44)
Andropogon hallii	x	x	0.14 (0.14)					
Aristida purpurea	x	x	10.3 (5.05)	4.09 (1.39)	2.35 (1.09)	3.77 (1.83)	1.71 (0.89)	2.48 (1.19)
Bouteloua curtipendula	x	x	0.34 (0.22)	0.56 (0.56)		0.57 (0.29)		
Bromus inermis				0.14 (0.14)	0.16 (0.16)	0.14 (0.14)		0.15 (0.15)
Bromus tectorum					0.07 (0.07)			
Elymus canadensis	x	x	0.73 (0.29)	1.14 (0.70)	0.53 (0.44)	1.66 (0.95)	1.24 (0.64)	
Elymus lanceolatus	x	x		0.15 (0.15)	0.18 (0.18)			
Elymus trachycaulus	x	x			0.07 (0.07)	3.98 (3.44)	0.32 (0.21)	1.06 (1.06)
Elymus sp			0.30 (0.30)	0.22 (0.22)		0.22 (0.22)	0.15 (0.15)	
Nassella viridula	x	x	0.13 (0.13)		0.36 (0.23)			
Pascopyrum smithii	x	x	1.14 (0.86)	1.55 (0.74)		2.99 (1.42)	1.26 (0.65)	0.18 (0.18)
Panicum virgatum	x	x	0.15 (0.15)			0.34 (0.22)		
Schizachyrium scoparium	x	x	0.41 (0.28)	0.32 (0.32)		0.18 (0.18)		
SHRUB								
Artemisia filifolia		x	0.30 (0.30)					

Artemisia cana		x			0.18 (0.18)			
Artemisia frigida	x	x	0.15 (0.15)	0.38 (0.24)	1.31 (0.77)	0.15 (0.15)	1.44 (0.77)	0.16 (0.16)
Artemisia ludoviciana	x	x					0.30 (0.19)	
Arctostaphylos pilosula		x				0.15 (0.15)		
Atriplex canescens	x	x					0.29 (0.18)	
Chrysothomnus viscidiflorus	x	x	0.16 (0.16)			0.18 (0.18)		
Cirsium arvense			0.32 (0.32)					
Ericameria nauseosa	x	x		0.36 (0.24)	0.28 (0.19)	1.37 (0.78)	0.15 (0.15)	0.77 (0.39)
Gutierrezia sarothrae	x	x	0.31 (0.31)	0.63 (0.34)	0.31 (0.31)	0.89 (0.47)	0.36 (0.23)	0.40 (0.40)
Prunus andersonii		x						0.22 (0.22)
Purshia tridentata	x	x					0.14 (0.14)	
Rhus trilobata	x	x			0.16 (0.16)			
Silphium albiflorum		x				0.15 (0.15)	0.26 (0.26)	

PLANT DENSITY DATA

Appendix 5. Mean and (standard error) of plant density values for all seeded species encountered in five treatments: grass (G), grass forb (GF), grass forb shrub (GFS), grass perches (GP), and grass shrub (GS). Data were collected in August 2013. Species were not present where values are missing.

	TREATMENTS				
	G	GF	GFS	GP	GS
FORB					
Argemone polyanthemos		0.10(0.10)			
Astragalus drummondii		0.86(0.56)			
Chenopodium album		0.19(0.12)			
Cheome serrulata		0.48(0.19)	0.29(0.20)		
Echinacea angustifolia	0.57(0.31)				
Helianthus annuus		1.62(0.46)	0.57(0.23)		
Hedysarum boreale		0.20(0.20)	0.20(0.20)		
Machaeranthera tanacetifolius			0.20(0.20)		
Penstemon angustifolius		0.76(0.23)			
Polygonum pensylvanicum		0.20(0.20)			
Sphaeralcea coccinea		0.38(0.38)	0.19(0.19)		
Thelesperma filifolium		0.19(0.12)			

GRASS					
Achnatherum hymenoides	0.48(0.24)	0.48(0.19)	0.10(0.10)	0.95(0.54)	0.57(0.23)
Andropogon gerardii	0.28(0.20)	0.19(0.12)	0.19(0.19)	0.57(0.31)	0.48(0.19)
Aristida purpurea	4.11(1.99)	2.86(1.28)	4.67(2.62)	2.10(0.83)	0.87(0.66)
Bothrioghloa barbinodis				0.10(0.10)	
Bouteloua curtipendula	0.29(0.20)			0.38(0.20)	
Bouteloua dactyloides	0.10(0.10)	0.10(0.10)			
Bouteloua gracilis	0.19(0.19)	0.10(0.10)		0.29(0.13)	0.29(0.29)
Elymus Canadensis	0.19(0.12)	0.29(0.20)	0.20(0.12)	0.67(0.25)	0.10(0.10)
Elymus elymoides	0.19(0.12)			0.19(0.12)	0.19(0.12)
Elymus trachycaulus	0.20(0.20)	0.38(0.20)		0.57(0.31)	0.19(0.12)
Hesperostipa comate		0.29(0.29)	0.38(0.29)		0.20(0.20)
Pascopyrum smithii	1.24(0.49)	0.29(0.13)	0.20(0.20)	0.57(0.20)	0.20(0.20)
Panicum virgatum	0.20(0.20)				
Pleuraphis jamesii	0.29(0.13)	0.20(0.12)	0.20(0.20)	0.19(0.19)	0.20(0.20)
Schizachyrium scoparium	0.29(0.29)	0.38(0.38)	0.29(0.20)	0.86(0.24)	0.19(0.12)
Setaria macrostachy				0.20(0.20)	0.20(0.20)
Sporobolus airoides				0.20(0.20)	
Sporobolus cryptandrus		0.20(0.20)			

Nassella viridula	0.57(0.27)	0.20(0.20)	0.19(0.12)	
SHRUB				
Amelanchier utahensis				0.10(0.10)
Atriplex canescens				0.19(0.19)
Chrysothamnus viscidiflorus				0.10(0.10)
Ericameria nauseosa	0.20(0.20)			
Gutiemezia sarothrae		0.20(0.20)		0.20(0.20)
Prunus virginiana		0.20(0.20)		
Purshia tridentata		0.29(0.20)		0.67(0.21)
Rhus trilobata		0.20(0.20)		0.20(0.20)
Yucca glauca		0.19(0.19)		0.20(0.20)

Appendix 6. The number of insect individuals within taxonomic orders caught by Drop-trap method in August, 2015.

Group	Individuals
Taxonomic orders:	
Coleoptera (beetles)	7
Diptera (true flies)	2
Hemiptera (true bugs)	6
Homoptera (leafhoppers, cicadas)	28
Hymenoptera (ants)	7
Hymenoptera (bees, wasps)	1
Orthoptera (grasshoppers, crickets)	1
Total	52

Appendix 7. The number of insect individuals within taxonomic orders caught by Pitfall -trap method in August, 2015.

Group	Individuals
Taxonomic orders:	
Coleoptera (beetles)	587
Diptera(true flies)	37
Hemiptera (true bugs)	12
Homoptera (leafhoppers, cicadas)	1
Hymenoptera (ants)	785
Hymenoptera (bees, wasps)	58
Isoptera (termites)	1
Lepidoptera (butterflies, moths)	2
Orthoptera (grasshoppers, crickets)	127
Total	1610

Appendix 8. The number of insect individuals within taxonomic orders method caught by Pan-trap method in August 2015.

Group	Individuals
Taxonomic orders:	
Blattodea (cockroaches)	1
Coleoptera (beetles)	143
Diptera(true flies)	243
Hemiptera (true bugs)	7
Homoptera (leafhoppers, cicadas)	1
Hymenoptera (ants)	42
Hymenoptera (bees, wasps)	237
Lepidoptera (butterflies, moths)	12
Orthoptera (grasshoppers, crickets)	2
Thysanoptera	332
Total	1020

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