CREATING BETTER WORKING LANDSCAPES IN POST-CONSERVATION RESERVE PROGRAM (CRP) LANDS: PROMOTING BUTTERFLY AND FLORAL RESOURCE POPULATIONS THROUGH PATCH-BURN GRAZING (PBG) AND OVER-SEEDING

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

By

Kimberly Joy Zralka

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Range Science

April 2022

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Torre J. Hovick
Chair

Jason P. Harmon

Benjamin A. Geaumont

Approved:

April 14, 2022 — Torre J. Hovick

Date — Department Chair

ABSTRACT

Declines in pollinator populations are a concern globally, and more information is needed to help conserve them. We studied how post-Conservation Reserve Program (CRP) lands could be managed as pollinator habitat. Our study occurred in Hettinger, ND from 2017-2021. We assessed the effects of patch-burn grazing on butterflies and floral resources. We also assessed the success of over-seeding to enhance flowering resources utilized by butterflies. We found that different butterfly species exhibited site selection based on time-since-fire, indicating that patch-burn grazing may be an effective grassland management method for creating diversity. We also found that grazer species (sheep or cattle) was influential on butterfly and vegetative communities. Our over-seeding efforts yielded low seedling establishment, but models indicated that drought and herbivory potentially influenced this. Overall, our results suggest that post-CRP working landscapes may benefit pollinators, but there are many challenges to create more forb-rich environments in these low diversity landscapes.

ACKNOWLEDGMENTS

This project was funded by U.S. Fish and Wildlife Service and North Dakota Game and Fish Section 6 Funding. Hettinger Research Extension Center provided logistical support and maintained grassland disturbances necessary for this research. The authors are much obliged to Jasmine Cutter, Tiffany Perron, Caitlin Brett, Anne Benson, Jonathan Spiess, C.K. Pei, Alex Rischette, and Jacob Yetter for their help with data collection. The authors give a special thanks to Justin Clarke, Esben Kjaer, and Evalynn Trumbo for their statistical support. Thank you to Hailey Keen, Bethany Roberton, Ellysa Johnson, Tucker Lutter, and Savannah Adams for all of the other support they gave during the course of this whole project. Lastly, thank you to Mike King and the rest of my family for all of their unending emotional support.

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Introduction

Biodiversity loss has resulted in a reduction in ecosystem services and stability worldwide (Cardinale et al 2012, Fuhlendorf et al 2012). This phenomenon is exemplified by the global crisis for pollinators (Potts et al 2009). Pollinators, particularly bees and butterflies, are critical to the stability of native ecosystems as well as global food security (Gallai et al 2009, Potts et al 2009). It is estimated that about one third of human food (both plant and animal products) depends on insect pollination (Aizen et al 2009). There are many factors that contribute to the pollinator decline, such as landscape fragmentation, pesticide use, and mismanagement; however, habitat loss is arguably the main cause (Rathcke and Jules 1993, Potts et al 2010, Thomas et al 2004, Briggler et al 2017). Across much of North America, this loss of grasslands makes preserving and managing remaining grasslands very important to conservation (Vogel et al 2007, Ceballos et al 2010, Fuhlendorf et al 2012, Smith & Cherry 2014, Gurney et al 2015), but more information is needed to evaluate potential ways of doing this.

Although historically important for supporting many pollinator species (including many specialists) (Vogel et al 2007, Smith & Cherry 2014), grasslands are some of the most threatened ecosystems in the world (Vogel et al 2007, Ceballos et al 2010, Fuhlendorf et al 2012, Gurney et al 2015). Currently, only 20% of North America's grasslands remain undeveloped, with much of what remains used for livestock grazing (Ceballos et al 2010). Besides development, grasslands face many other threats that also affect pollinator populations. Specifically, as land is developed for human use and homogenization increases, invasive species can overrun remaining grasslands and cause greater biodiversity losses (Vogel et al 2007, Ceballos et al 2010, Fuhlendorf et al 2012). Increased use of agricultural pesticides and herbicides in grassland regions has also been detrimental to grasslands and many pollinator populations (Kluser & Peduzzi 2007, Potts et al 2010, Thogmartin et al 2017). The combination of intensified agriculture and changes plant community composition has significantly reduced the availability of nectaring and nesting resources for pollinators (Blaauw & Isaacs 2014). Overall, with present management practices, much of the historically important U.S. grassland region is no longer as valuable in supporting pollinator populations currently (Smith et al 2016).

Partly to help overcome long-term degradation of agricultural land, the U.S. Department of Agriculture's Conservation Reserve Program (CRP) was established in 1985 (United States Department of Agriculture Farm Service Agency 2021). This program paid private landowners to plant their marginal lands with perennial vegetation, often grasses, and leave the land unmanaged for a period of 10-15 years (United States Department of Agriculture Farm Service Agency 2021). The main goal of this program was to help reduce soil erosion, but grassland establishment and in turn provisioning of wildlife habitat were secondary results (United States Department of Agriculture Farm Service Agency 2021). At the peak of the CRP, over 36 million acres of land were enrolled (Skaggs et al 1994, Cooper & Osborn 1998, Chang & Boisvert 2009, Sullivan et al 2011, United States Department of Agriculture Farm Service Agency 2021). However, once done with the program, much of this previous CRP land has not been re-enrolled in the program due to less appealing financial incentives and a shrinking enrollment cap, leading to large quantities of land that may be managed for new goals (USDA-FSA, 2007, 2020). Frequently, CRP is converted back into cropland (Wu 2000), but there are other potentially more conservation-friendly options, such as creating working landscapes (lands that are dually managed for conservation and production purposes) (Polasky et al 2005, Bendel et al 2019).

Introducing livestock herbivory to post-CRP grasslands can create working landscapes by providing financial benefits to landowners while also supporting opportunities for biodiversity conservation. Working landscapes can generate revenue through livestock production while also improving ecosystem services through maintaining grassland cover and decreasing landscape fragmentation (Morandin et al 2007, Bendel et al 2019). This can provide a grassland management alternative for landowners other than row cropping. Yet how to effectively manage these lands to achieve multiple objectives is not yet clear. Previous work has demonstrated that managing working landscapes with the addition of patch-burn grazing (PBG) may be effective at promoting cattle production and pollinator conservation simultaneously (Cutter et al 2021, Cutter et al 2022).

Patch-burn grazing promotes heterogeneity throughout a landscape by using discrete patch fires that vary spatially and temporally while allowing grazing access to domestic herbivores (Fuhlendorf & Engle 2004). This differs from traditional rangeland management that aimed to minimize variation and maximize even utilization of forage (Fuhlendorf & Engle 2001, Fuhlendorf & Engle 2004). Pre-settlement landscapes, however, naturally developed as mosaics through disturbance events such as fire, grazing, and extreme weather (Fuhlendorf & Engle 2004, Ricketts & Sandercock 2016). PBG attempts to mimic this historic mosaic of vegetation structure (Engle et al 2008, Ricketts & Sandercock 2016). Specifically, smaller patches within the pastures are alternately burned from year to year (Fuhlendorf & Engle 2004, Ricketts & Sandercock 2016). Grazers are allowed full access to pastures and are naturally attracted to the recently burned areas (Fuhlendorf & Engle 2004, Ricketts & Sandercock 2016) (Fig. 1.1). This creates a mosaic composed of distinct patches of vegetative structure and composition, leading to a greater diversity of grassland types (Knopf 1994, Fuhlendorf & Engle 2004, Ricketts & Sandercock 2016). This diversity can potentially attract greater biodiversity, including greater pollinator diversity (Knopf 1994, Fuhlendorf & Engle 2004, Ricketts & Sandercock 2016, Cutter et al 2021, Cutter et al 2022). Additionally, this management technique has been shown to create resiliency to variable climatic conditions, which will become increasingly important to support pollinators and promote biodiversity as climate change progresses (Allred et al 2014, Spiess et al 2020, Cutter et al 2021, Cutter et al 2022). PBG has had limited application in the Northern Great Plains, so research examining post-CRP land here provides a unique opportunity to study PBG on lands that have received little past-management.

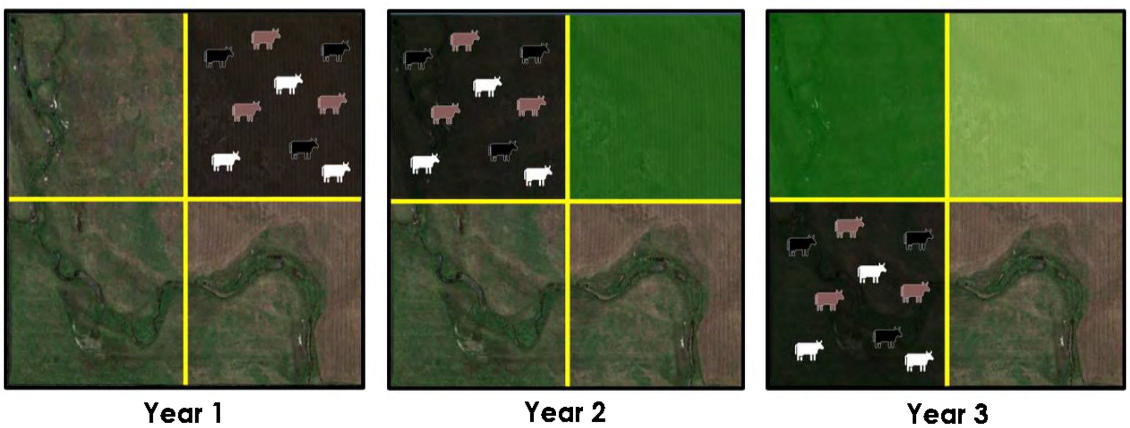

Figure 1.1: An example of patch-burn grazing. *The pasture is divided into patches and rotationally burned each year, yielding a mosaic structure. Livestock is allowed access to entire pasture, although they concentrate grazing in the most recently burned patch due to nutritious graze, and thus shift grazing concentration yearly (Helzer 2011).*

We assessed the influence of PBG on butterfly communities in post-CRP landscapes. Butterflies are an important suite of pollinating insects that also serve as a vital food source for other animals such as birds and small mammals (Sethy & Jena 2009). In fact, it has been suggested that monitoring butterfly community composition can be indicative of the health of other taxa groups, since butterflies require a variety of plant species and structures throughout their life cycle (Maccherini et al 2009, Woodcock et al 2012). Like many other pollinators, butterfly populations worldwide have declined recently (by 40% in the past 40 years), mainly due to habitat loss (Vogel et al 2007, Swartz et al 2015, Thogmartin et al 2017). However, it has been suggested that both landscape and local environmental variables influence habitat quality for butterfly species (Kral et al 2017), so factors other than habitat loss may be influencing the decline. Further investigation regarding butterfly-environmental interactions is warranted, as general assumptions of butterfly species habitat selection may not be accurate or applicable to all regions. Regional as well as site specific factors need to be evaluated to improve butterfly conservation, particularly in marginal lands such as post-CRP lands.

The goal of our project was to gain a greater understanding of the effects of PBG as a working grassland management technique on butterfly and floral resource communities in Hettinger, ND. Previous work in this same system has been done in the past, and it determined that grazer species (sheep versus cattle) distinctly impacted pollinator and floral resource communities, with cattle-grazed sites hosting a greater abundance and richness of both (Cutter et al 2021, Cutter et al 2022). However, those studies took place during the early stages of the PBG management implementation; a complete fire return interval hadn't yet been achieved at any sites. As we have continued to manage these sites with PBG and now have succeeded in completing a full fire return interval at all, we wanted to determine if this relationship remained. Additionally, we wanted to build off of this previous work to further explore the relationship between the length of time since a patch was burned (time-since-fire (TSF)) and the floral and butterfly communities in these post-CRP pastures. Our specific objectives were to: (1) Determine TSF site selection for butterflies, (2) Determine the effect of TSF within the PBG framework has on floral resource and butterfly community composition, (3) Determine the influence of PBG on overall vegetation composition and structure, and (4) Determine the effect of grazer type (sheep versus cattle) on floral resource and butterfly community distribution with PBG.

Methods

Study Area

This study took place on privately owned land located in the southwestern corner of North Dakota in Adams County, near the town of Hettinger (46^{O}0'11.8"N, -102^{O}38'37.3194"W) (Fig. 1.2). The main industries in this area are crop and livestock production, so further development of sustainable grazing practices is especially relevant (USDA NASS 2019, Cutter et al 2021). The 30-year temperature average for the study season (May-August) ranged from 12-21^{O}C per month, but the temperature average during the specific years this study occurred ranged from 16-19^{O}C per month (Average Temperature (1981-2010) 2021, NDAWN 2021). The 30-year precipitation average for the study season ranged from 4.45-7.62cm per month with the average precipitation level during the specific study years ranging from 2.80-8.31cm per month (NDAWN 2021, Precipitation (1981-2010) 2021). According to the National Integrated Drought Information System, the study seasons of 2017, 2018, 2020, and 2021 were characterized by moderate-exceptional drought. In contrast, the 2019 study season experienced moderately wet conditions (Drought Conditions for Adams County 2021).

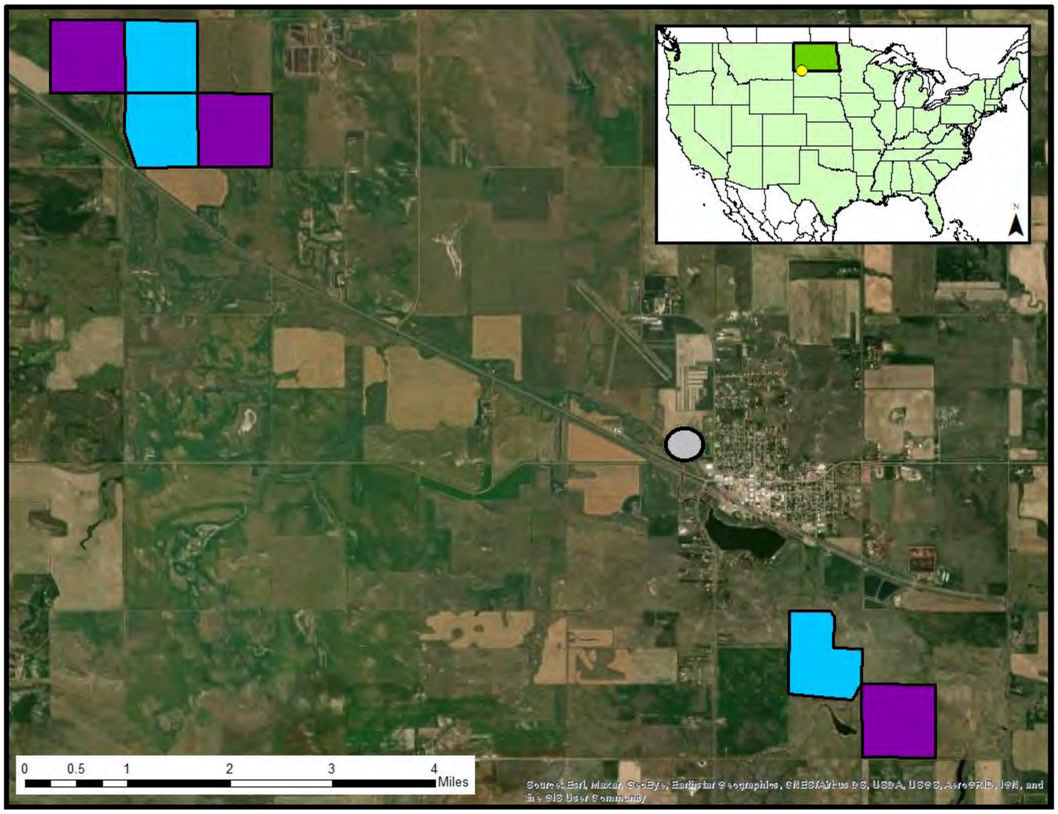

Figure 1.2: A map of the study site. *Hettinger, ND is displayed in yellow in the smaller inlaid map. In the larger map, the Hettinger Research Extension Center (HREC) is displayed in grey. The blue polygons indicate sheep pastures, and the purple polygons indicate cow pastures.*

Our work was accomplished on former Conservation Reserve Program fields that were planted in the 1980's with introduced vegetation such as intermediate wheatgrass (*Elymus hispidus* (Opiz) Melderis), alfalfa (*Medicago sativa* L.), crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), and yellow sweet clover (*Melilotus officinalis* L.) (Geaumont et al 2017). More recently, the pastures retain low diversity and are dominated by plants included during original CRP seeding (Cutter et al 2021).

Treatment Design

The study was located on 6, 65-ha pastures, 4 of which (2 sheep and 2 cattle) are located 7 kilometers west of Hettinger, and the other 2 pastures (1 sheep and 1 cattle) are 3 kilometers south of Hettinger (Fig. 1.2). Sheep-grazed pastures were stocked with Rambouillet ewes (*Ovis aries* L.; 2–5 yrs old), and cattle-grazed pastures were stocked with cow-calf pairs (*Bos taurus*

L.). Pastures were stocked at a rate of (0.5–0.6 ha AUM −1 (animal unit month) from June to mid-September each year (Spiess et al 2020, Cutter et al 2021). Each pasture was divided into 4 patches by mineral dirt fire breaks, and one patch was burned each year, similar to other patch-burn grazing studies from the region (Vermeire et al 2004, Augustine & Derner 2014) (Fig. 1.3). Burning began in the fall of 2016 at the onset of this study; the sites were unburned previously. Each patch of each pasture was burned at least once during the course of this study. Within each treatment replicate (i.e. burn patch), we randomly laid out 3, 100-meter transects in each pasture (12 transects per pasture), for a total of 72 transects across the study (Fig. 1.3). These same transects were utilized for both butterfly and floral resource surveys (as detailed in *Floral Resource Surveys* and *Butterfly Surveys* sections below).

Figure 1.3: A map of a post-CRP pasture and the transects surveyed during this study. *The pasture is divided into the four burn patches (as indicated by the yellow central cross of the pasture), which will be rotationally burned yearly. Each of the white lines represents a transect survey location. Transects were 100 meters long and randomly distributed throughout all six pastures.*

Floral Resource Surveys

We assessed floral resources at each pasture once per month from June-August to allow for detection in seasonal shifts of flowering plant phenology (Cutter et al 2021). We conducted floral resource surveys immediately following butterfly surveys along the same transects (see *Butterfly Surveys* section). We used a belt transect survey method, identifying, counting, and logging every blooming stem within 1 meter on either side of the transect.

Butterfly Surveys

We assessed butterflies annually in each pasture once per month (June-August) to detect the seasonal shifts of butterfly populations using a line transect method (Brown & Boyce 1998, Buckland et al 2001, Cutter et al 2021). Surveys took place between 08:00-17:30 with temperatures ranging between 18.3-35.5°C, sustained winds <20km/hr, and cloud cover < 50% (Moranz et al 2012, Harmon-Threatt & Hendrix 2015, Cutter et al 2021). These parameters allowed surveys to take place during maximum butterfly activity levels, thus maximizing survey effectiveness.

During a single survey, we walked the 100 meter transect for a duration of 10 meters per minute (monitored by a timer) with the use of a handheld GPS unit. We identified butterflies with binoculars and logged observed butterflies and the perpendicular distance from the transect. We measured distance from the transect using a Leupold RX-1000 TBR range finder (± 0.5 meters) for butterflies over 10 meters away. Closer observations were visually estimated (Moranz et al 2012, Cutter et al 2021). We paused the timer and left the transect to capture any unknown species with a butterfly net, identified the individual, and released it before returning to the transect and resuming the survey (Moranz et al 2012, Cutter et al 2021).

Vegetation Composition & Structure Surveys

We conducted assessments of plant community composition and vegetative structure once a year during peak growth. We laid down a measuring tape of 100 meters at each transect and conducted 22 surveys on each. We conducted each survey one meter perpendicular to the transect line on each side every 10 meters. We used $0.25m^2$ quadrats to assess the average Daubenmire cover class (0–5%, 5–25%, 25–50%, 50–75%, 75–95%, 95–100%) of the following factors: Bare Ground, Ground Litter, Standing Litter, Grass Cover, Forb Cover, and Sedge Cover (Daubenmire 1959). Additionally, within each quadrat, we used a Robel pole marked every 0.25dm to measure visual obstruction (VOR) (Robel et al 1970), litter depth, tallest standing living vegetation, and tallest standing dead vegetation (Cutter et al 2021).

Data Analysis

Site selection ratio tests in a design 1 framework with known proportions were conducted in R on the six most commonly observed butterfly species to evaluate TSF patch selection (Duquette et al 2020). We defined availability as the entirety of our study area. We calculated selection ratios as ($\hat{w}i=oi/\pi i$) where oi is the proportion of the sample of occupied units in patch type i and πi represents the proportion of patch type i on the landscape (Duquette et al 2020). We calculated the standard error of $\hat{w}i$ as ($se(\hat{w}i)= \sqrt{}\ oi(1\text{-}oi)/(u+\pi i\ 2)$) where u represents the total number of butterflies in the sample (Duquette et al 2020). We plotted the TSF patch selection ratio for each year the study was conducted individually as well as the overall average to visualize year-to-year fluctuations as well as overall trends.

Despite the distinct impact grazer species can have on both abundance and richness, we wanted to isolate the impact that the PBG framework had on the post-CRP communities, and thus looked at the data set as a whole to conduct ordination analysis. We used the vegan package in R to determine the relationship between TSF patches and floral resource community composition using non-metric multidimensional scaling (NMDS) ordinations (Oksanen et al 2019).

We refined the data set to remove any single observations, ending in a community dataset containing 73 flowering forb species. We created our ordinations using the *metaMDS* function in ggord. Stress plots were used to verify the relationship between factors (stress < 0.2 showed a relationship). We used the same methodology to produce ordination plots assessing the butterfly communities within the TSF patches of the PBG mosaic framework, resulting in a butterfly community dataset containing 26 species. We assessed ordinations with PERMANOVA (function *adonis2*) to determine significant differences between communities in different TSF patches.

We plotted means of structural factors (such as VOR, maximum living & dead vegetation heights, and litter depth) and compositional factors (such as percent bare ground, ground litter, standing litter, sedge, grass, and forb composition) to visualize differences between TSF patches and explore further avenues of analysis. TSF patches were categorized as: Current (burned that year), 1 Year (burned one year previously), 2 Years (burned two years previously), 3 Years (burned three years previously), or Unburned (areas that hadn't been burned yet). We ran ANOVA tests (function *aov*) to determine significance of the overall models comparing the relationship between each structural and compositional factor of each TSF patch. Models with $p<0.05$ were determined to be significant. Within these models, we ran tukey post hoc tests (function *TukeyHSD*) to compare significant differences among individual factors within the TSF patches. Factors with a $p<0.05$ were determined to be significant.

Lastly, we plotted floral resource and butterfly community abundance and richness by grazer species to determine if differences in these communities matched those observed previously (Cutter et al 2021, Cutter et al 2022). To determine differences, we ran ANOVA tests (function *aov*) to determine significance of the overall models comparing the relationship between each floral resource abundance and butterfly abundance per pasture to grazer species. Models with $p<0.05$ were determined to be significant. We also ran tukey post hoc tests (function *TukeyHSD*) to compare significant differences among abundances within each grazer species. Factors with a $p<0.05$ were determined to be significant.

Results

Butterfly Site Selection

Site selection ratios showed different patch selection for each butterfly species (Fig. 1.4). Trends were not consistent from year to year, likely due to fluctuating weather conditions. However, overall average selection ratios indicated unique site selection for each butterfly species. Some species selected for the most recently burned patches, such as Clouded Sulphur (*Colias philodice* L.), while others chose for the greatest time post fire patches, such as Checkered White (*Pontia protodice* (Boisduval & Leconte)). Some species, such as Melissa Blue (*Lycaeides Melissa* (W.H. Edwards, 1873)), selected for the most recently and greatest time post fire burned patches. Additionally, many species selected against, or avoided, specific burn patches.

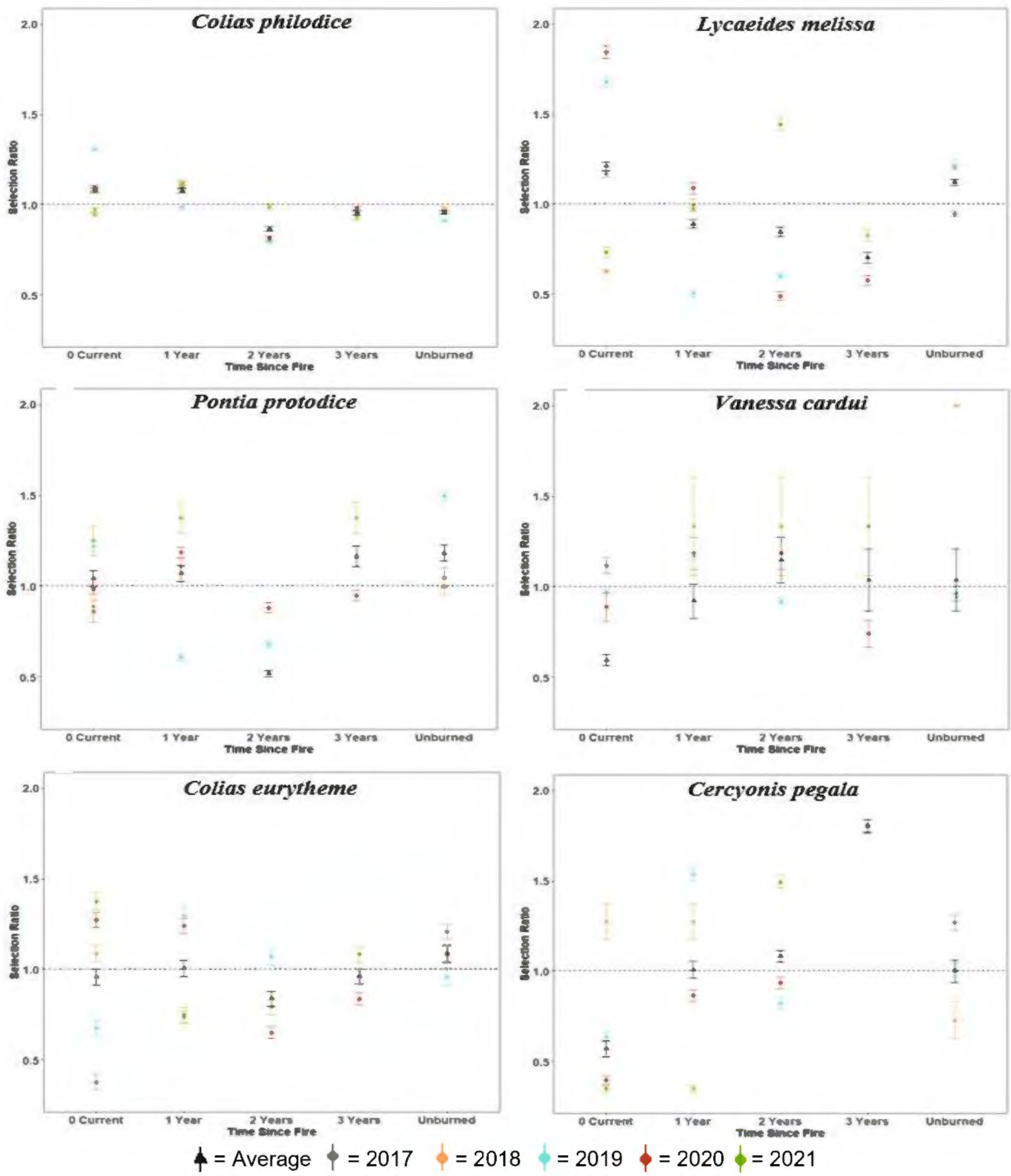

Figure 1.4: Site selection ratios assessing TSF patch selection across all pastures of the six most commonly observed butterfly species each year (2017-21) as well as on average. *Different species selected for (above the dotted line) and against (below the dotted line) different TSF patches, while other demonstrated no selection (confidence intervals overlap 1.0). Black triangles represent the average site selection ratio for each TSF patch, grey circles represent site selection ratios from 2017, orange circles represent site selection ratios from 2018, aqua circles represent site selection ratios from 2019, red circles represent site selection ratios from 2020, and light green circles represent site selection ratios from 2021.*

Effects of Fire on Floral Resource & Butterfly Communities

We observed 108 species of flowering forbs during this study and a total of 312,297 flowering stems (see Table A.1 in Appendix A). The most commonly observed flowering species was alfalfa which composed 69% of the overall flowering resource community, followed by yellow sweet clover, which made up 14% of the available flowering resources. The Other 106 species observed composed approximately 17% of the flowering resource community. The resulting ordination of all observed flowering forb species revealed distinct communities within the different TSF burn patches (stress=0.16, r^2=0.24, p=0.01) (Fig. 1.5). This ordination explained 98% of variation (non-metric fit r^2=0.975).

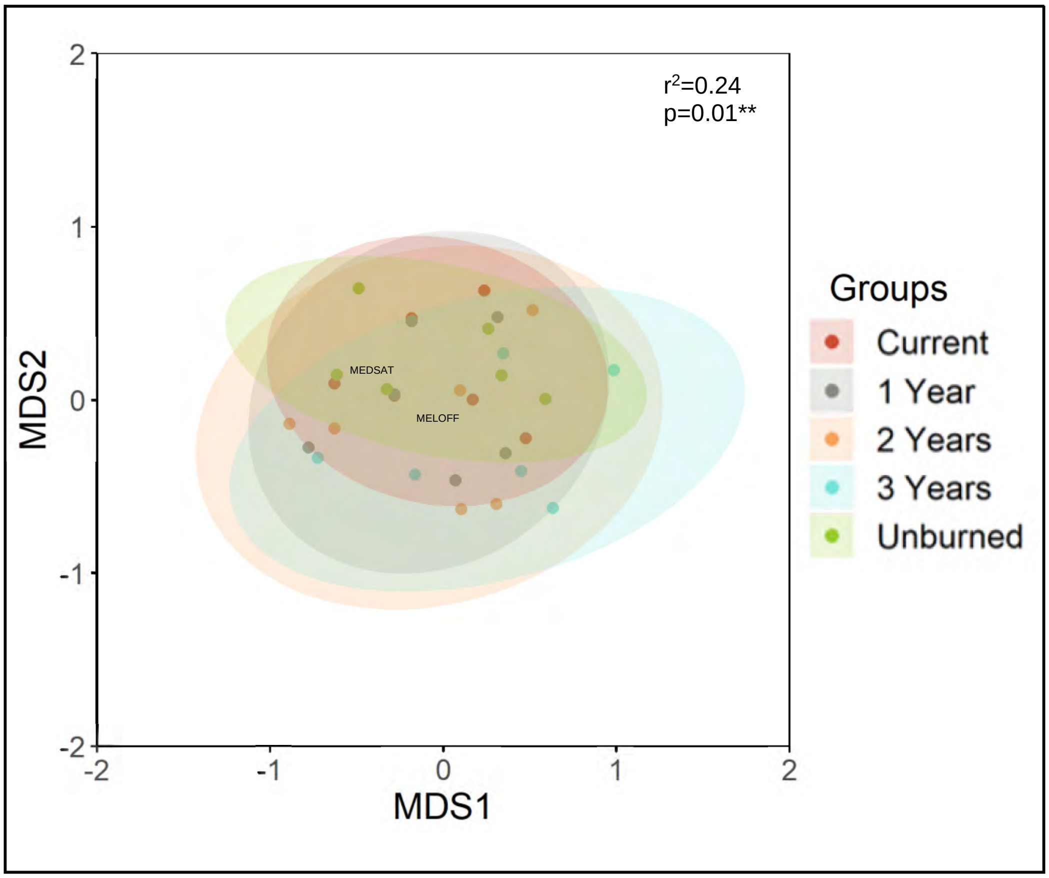

Figure 1.5: The relationships between floral resource species in different TSF burn patches in post-CRP landscapes. *"Current" (red) indicate areas burned that season, "1 Year" (grey) indicates areas burned one year ago, "2 Years" (orange) indicates areas burned two years ago, "3 Years" (aqua) indicates areas burned three seasons ago, and "Unburned" (light green) indicates never burned areas.*

We observed approximately 27 species of butterflies throughout the course of this study, with a total of 17,7581 individuals (see Table A.2 in Appendix A). Common species often associated with agricultural environments composed the majority of the overall butterfly community. Clouded Sulphur observations made up 58% of the observed butterfly community. Twenty one of the 27 species identified had few observations, making up only 10% of the overall butterfly community. However, species of conservation concern, such as Monarchs (*Danaus plexippus* L.*)* and Regal Fritillaries (*Speyeria Idalia* (Drury)), were observed. The resulting ordination of all observed butterfly species revealed distinct communities within the different TSF burn patches (stress=0.13, r^2=0.61, p=0.001) (Fig. 1.6). This ordination explained 98% of variation (non-metric fit r^2=0.982).

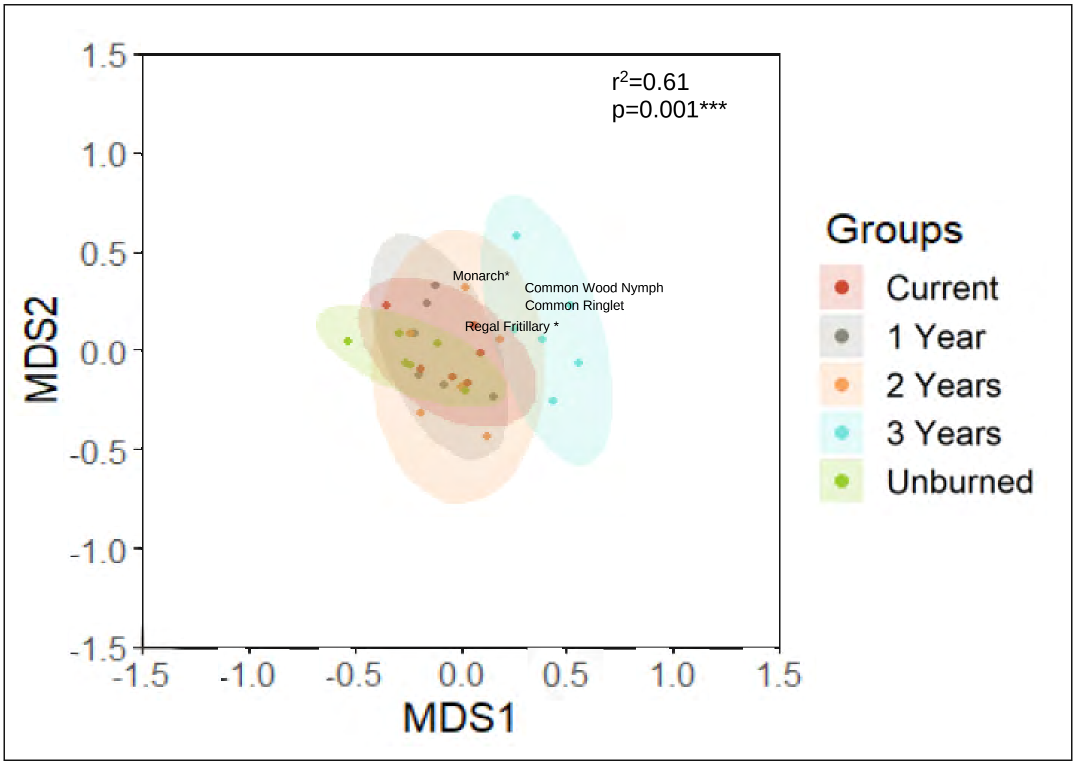

Figure 1.6: The relationships between butterfly species in different TSF patches in post-CRP landscapes. *"Current" (red) indicate areas burned that season, "1 Year" (grey) indicates areas burned one year ago, "2 Years" (orange) indicates areas burned two years ago, "3 Years" (aqua) indicates areas burned three seasons ago, and "Unburned" (light green) indicates never burned areas. Species of conservation concern are denoted with a (*).*

Overall Landscape Composition & Structure

The patch-burn grazing management framework created distinct grassland habitats within each TSF patch (Fig. 1.7). In regards to VOR, the 3 Years TSF patches had the greatest VOR, and the Unburned patches had the lowest VOR. The 2 Years TSF patch was not significantly different from the Current and 1 Year TSF patch, however all other patch relationships were significant (df=7909, f=97.43, p=<0.000). For maximum live vegetation height, the 3 Years TSF patches had the greatest height, and the Unburned patches had the lowest. All maximum live vegetation heights for all TSF patches were significantly different from one another except when comparing the Year 1 TSF patch to the Unburned patch (df=7909, f=92.99, p=<0.000). For maximum dead vegetation height, the 3 Years TSF patches had the greatest height (dm), and the 2 Years TSF patches had the lowest. All maximum dead vegetation heights for all TSF patches were significantly different from one another (df=7909, f=703.5, p=<0.000). For litter depth (dm), the 1 Years TSF patches had the greatest depth, and the Current patches had the lowest. All litter depths for all TSF patches were significantly different from one another (df=7909, f=303.1, p=<0.000).

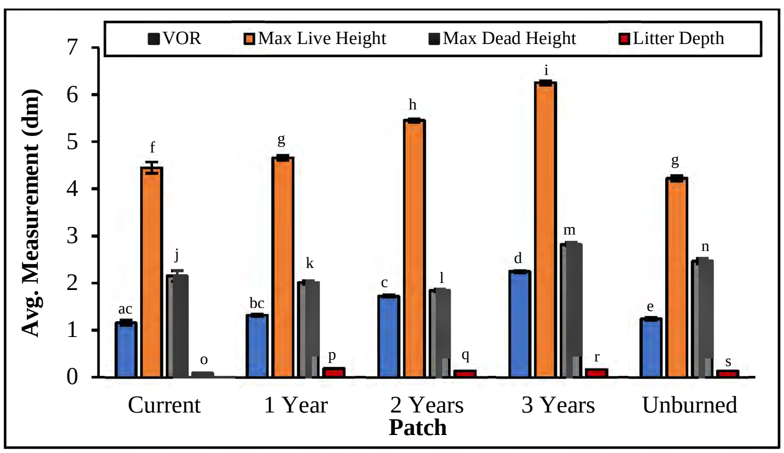

Figure 1.7: An overview of the average structural factors associated with each TSF patch across all study sites during the full course of this study (2017-21). *Error bars represent standard errors. Letters "a" through "s" represent statistically different values when comparing each TSF patch factor the same factor in all TSF patches. The same letters over multiple bars shows that those values are not statistically different.*

Compositionally, differences were also observed across all TSF patches (Fig. 1.8). For bare ground cover, the Current TSF patches had the highest percent cover, and the 3 Year TSF patches had the lowest. The 2 Years TSF patch was not significantly different from the 3 Years or the Unburned TSF patches, and the 3 Years TSF patch was not significantly different from the Unburned patches in regards to percent bare cover, but all other patch relationships were significantly distinct (df=6329, f=163.1, p=<0.000). For ground litter, the Current TSF patches had the highest percent cover, and the Unburned TSF patches had the lowest. The 2 Years TSF patch was not significantly different from the 1 Year TSF patch in regards to ground litter cover, but all other patch relationships were significantly different (df=6329, f=219.7, p=<0.000). For standing litter, the 3 Years TSF patches had the highest percent cover, and the Unburned TSF patches had the lowest. The 2 Years TSF patch was not significantly different from the 3 Years or the Unburned TSF patches, and the 3 Years TSF patch was not significantly different from the Unburned patches in regards to percent standing litter cover, but all other patch relationships were significantly distinct (df=6329, f=209.8, p=<0.000). For grass cover, relationships weren't as distinct. The 3 Years TSF patch was not significantly different from the 1 Year, 2 Years, or the Unburned TSF patches, and the 2 Years TSF patch was not significantly different from the Unburned patches in regards to percent grass cover, but all other patch relationships were significantly distinct (df=6329, f=24.25, p=<0.000). For forb cover, the Unburned TSF patches had the highest percent cover, and the 3 Years TSF patches had the lowest. The Current TSF patch was not significantly different from the 1 Year or 2 Years TSF patches, and the 2 Years TSF patch was not significantly different from the 1 Year TSF patches in regards to percent forb cover, but all other patch relationships were significantly distinct (df=6329, f=377.5, p=<0.000). Lastly, sedge cover was low across all patches. The 3 Years TSF patch was significantly different from the Current, 1 Year, and 2 Years TSF patches, but all other patch relationships were *not* significantly distinct (df=6329, f=26.94, p=<0.000).

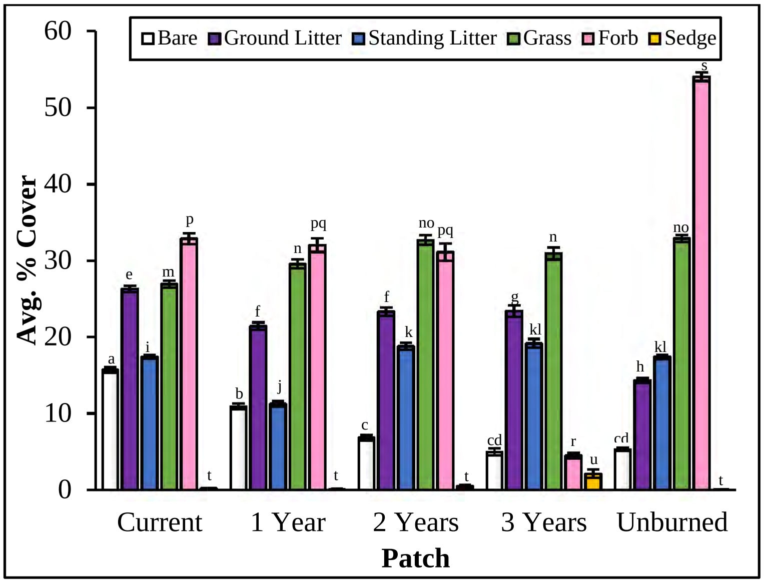

Figure 1.8: An overview of the average compositional factors associated with each TSF patch across all study sites during the full course of this study (2017-21). *Error bars represent standard errors. Letters "a" through "u" represent statistically different values when comparing each TSF patch factor the same factor in all TSF patches. The same letters over multiple bars shows that those values are not statistically different.*

Grazing Species Influences

Grazer species (sheep or cattle) had a distinct impact on the flowering resource abundance (Fig. 1.9A). Overall, cattle-grazed pastures boasted a greater number of flowering stems per pasture than sheep pastures (df=7909, f=87.11, p=<0.000), with twelve-times the number of total stems per transect on average. Grazer species did not have as distinct of an impact on butterfly communities. Cattle pastures hosted the greatest abundance of individual butterflies per pasture, however this difference was not statistically significant (df=7909, f=0.12, p=0.73). Cattle-grazed pastures also hosted about twice the number of flowering forb species as sheep-grazed pastures (Fig. 1.9B). Cattle pastures also had a slightly larger number of butterfly species as compared to sheep pastures, although difference was only four species.

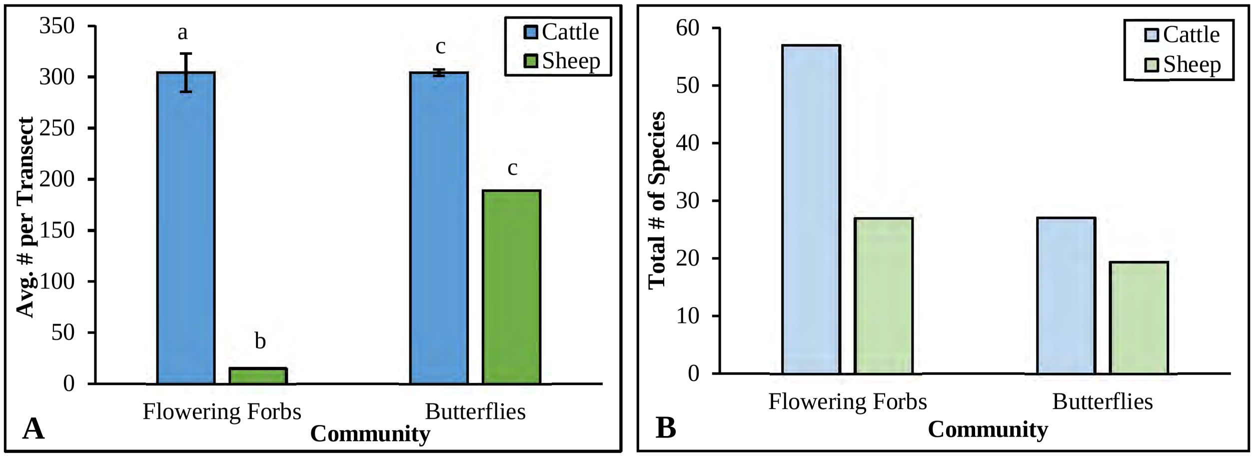

Figure 1.9: The effects of grazer species on butterfly and floral resource communities across all TSF patches within all study sites during the course of this study (2017-21). *A: The average abundance of flowering forb stems and butterflies per transect in sites grazed by cattle versus sheep. Error bars represent standard errors. "a", "b", and "c" represent significantly distinct values. B: The total number of flowering forb and butterfly species detected in sites grazed by cattle versus sheep.*

Discussion

This is one of the first studies to document site selection in insects in regards to TSF patches in a PBG managed system. There have previously been some oviposition preference studies that utilized site selection, but they were not conducted in a PBG managed system (Konvička & Kuras 1999, Braem et al 2021). Site selection of TSF patches within patch-burn grazing management has been commonly observed in other species in similar grassland systems, particularly in birds (McNew et al 2015, Skagen et al 2018, Duquette et al 2020, Kraft et al 2021). However, a greater understanding of TSF patch selection among pollinators will potentially help conservationists better plan grassland management in the future. Within post-CRP pastures, site selection ratios indicated unique TSF patch selection by each butterfly species. This is likely due to the different life history requirements each species has, such as unique host plants (forbs or grasses) and nectaring resource needs (Moranz et al 2012). Additionally, there were distinct floral resource (compositionally and structurally) and butterfly communities that occupied each TSF patch. We also observed differences in butterfly and floral communities in pastures grazed by sheep versus cattle, with cattle pastures boasting greater biodiversity. Overall, the results of this study can be used to improve grassland management practices in the Northern Great Plains, particularly on post-CRP land.

As shown in the floral resource ordination plot, a statistically distinct floral resource community was observed in each TSF patch. This is similar to what has been documented previously in other grassland systems (Vermeire et al 2004, Augustine & Derner 2015, Ricketts & Sandercock 2016, Briggler et al 2017). Yellow sweet clover, an introduced species that has been shown to deter the growth of other native forbs (Wolf et al 2003, Dickson et al 2010), was prevalent at all sites. However, the extreme drought of the 2021 field season (Average Temperature (1981-2010) 2021, Drought Conditions for Adams County 2021), greatly reduced yellow sweet clover cover (Table A.1). This will potentially open up more space for the establishment of what native forbs remain in the seedbank (if any), possibly creating a more diverse flowering forb community to better serve the pollinators of the Northern Great Plains region (Fuhlendorf & Engle 2004). Additionally, encroachment of agricultural invasives such as field bindweed (*Convolvulus arvensis* L.), leafy spurge (*Euphorbia esula* L.), and field pennycress (*Thlaspi arvense* L.) likely played a role in shaping the floral resource community, although their numbers are currently relatively low (Table A.1) (Lym 1998, Bergquist et al 2007, Jacobs 2007). Overall, forb biodiversity will likely continue to increase as prescribed fire continues to be used and precipitation levels return to normal, improving pollinator resources and habitat for other native grassland organisms as time goes on (Cane and Tepedino 2001).

The overall butterfly community of these post-CRP pastures was dominated by common, agricultural species. There were grassland specialists and species of concern observed in these pastures, but the community was dominated by common, agricultural species likely due to the overall low grassland quality and limited flower diversity of the surrounding areas. Nonetheless, our ordination plot concerning the common butterfly species we observed showed that each TSF patch had a statistically distinct butterfly community. It is important to note that grassland specialist species, such as Common Wood Nymph (*Cercyonis pegala* (Fabricius)) and Common Ringlet (*Coenonympha tullia* (Müller)), are prominently shown in the 3 Years TSF patch ellipsis of the ordination. As time goes on and the use of PBG continues in these sites, we expect to see increases in utilization of these areas by grassland specialists and species of concern as the number of flowering forbs increases and overall structure diversifies (Fuhlendorf & Engle 2004). Even so, the results of this study show that post-CRP pastures are utilized as habitat by butterflies in this region. This is important to support the rest of the native grassland community in the region (Helzer 2011, Pillsbury et al 2011, Duchardt et al 2016, Kraft et al 2021), as keeping common species common helps support the rest of the food chain, and in time will likely result in more organisms using these sites (Gallai et al 2009, Potts et al 2009).

A mosaic of vegetation structure was achieved across all patches in the five years this study spanned. Significant differences between TSF patches were observed for all structural measurements. The most recently burned patches (Current, 1 Year) exhibited some of the least VOR, maximum living height, and maximum dead height. These differences support findings of previous studies, which found that the most recently burned patches exhibiting the overall shortest, least-obscured structures with the least amount of standing litter (Pillsbury et al 2011, Augustine & Derner 2015, Ricketts & Sandercock 2016, Sliwinski et al 2019). The least recently burned patches (2 Years, 3 Years) exhibited some of the highest VOR, maximum living height, and maximum dead height, matching what has been observed for less recently burned patches in previous studies (Pillsbury et al 2011, Augustine & Derner 2015, Ricketts & Sandercock 2016, Skagen & Augustine 2018). The patches that were unburned did not match these trends over time. This is likely due to the short amount of time that this treatment has been in effect on these landscapes (Duchardt et al 2016), as well as the extreme weather conditions that have been observed in recent years (Average Temperature (1981-2010) 2021, Drought Conditions for Adams County 2021). This highlights the importance of disturbance within grassland systems, and in turn validates patch-burn grazing as a management framework. Other studies have shown that most butterfly species are more abundant in areas with shorter, less-dense vegetation (Maccherini et al 2009, Woodcock et al 2012), however this is not the case for all species, so structural diversity is important in supporting butterfly populations.

A mosaic of vegetation composition was achieved across all patches in the five years this study spanned. Significant differences between TSF patches were observed for all structural measurements. The most recently burned patches (Current, 1 Year) exhibited some of the lowest VOR, maximum living height, and maximum dead height. These differences support findings of previous studies, which found that the most recently burned patches exhibiting the overall shortest, least-obscured structures with the least amount of standing litter (Pillsbury et al 2011, Augustine & Derner 2015, Ricketts & Sandercock 2016, Sliwinski et al 2019). The least recently burned patches (2 Years, 3 Years) exhibited some of the highest VOR, maximum living height, and maximum dead height, matching what has been observed for less recently burned patches in previous studies (Pillsbury et al 2011, Augustine & Derner 2015, Ricketts & Sandercock 2016, Skagen & Augustine 2018). This highlights the importance of disturbance within grassland systems, and in turn validates patch-burn grazing as a management framework. Other studies have shown that most butterfly species are more abundant in areas with shorter, less-dense vegetation (Maccherini et al 2009, Woodcock et al 2012), however this is not the case for all species, so structural diversity is important in supporting butterfly populations.

Each TSF patch also had its own vegetation composition, mirroring a mosaic landscape. Not every relationship within each TSF patch was statistically different, however the most recently burned patches (Current, 1 Year) had the greatest bare ground cover compared to the less recently burned patches, similarly to what has been observed in previous studies (Vogel et al 2007). Where grass cover did not differ greatly among patches, forb cover in the 3 Years TSF patch was drastically lower than the other patches. This is likely due to a few factors. First, the 3 Years TSF patch first occurred during 2020; there were only 2 years of data gathered for this TSF patch. The lower sample size (Duchardt et al 2016), in addition to the exceptional drought that occurred those years (Average Temperature (1981-2010) 2021, Drought Conditions for Adams County 2021), likely influenced forb establishment those years (Tilman & El Haddi 1992). As time goes on and the PBG management framework is continued, these results may differ in the future, and more forbs in the 3 Years TSF patches may be observed. The patches that were unburned did not match these trends over time. This is likely due to the short amount of time that this treatment has been in effect on these landscapes, as well as the large abundance of yellow sweet clover and alfalfa that occurred at those patches, as those were included in the original CRP seed mix (Geaumont et al 2017). Continuing PBG across these sites will likely help keep forb and grass abundance in balance, maintaining a healthy grassland to support native pollinators and other organisms.

Grazer species had a distinct impact on both the floral resource and the butterfly communities. Sites grazed by sheep reduced both floral abundance and richness as compared to cattle-grazed sites. This is likely due to the differing feeding mechanisms of sheep and cattle.

Sheep are known to be more selective grazers often selecting for forbs, due to the increased energy burned during feeding due to their overall smaller size (Fuhlendorf & Engle 2004, Helzer 2011, Ricketts & Sandercock 2016, Cutter et al 2021, Cutter et al 2022). Cattle are more often observed feeding on grasses rather than seeking out flowering forbs (Helzer 2011, Cutter et al 2021, Cutter et al 2022). These differing feeding mechanisms are likely the reason the sites grazed by sheep had lower floral resource availability and richness than cattle-grazed pastures. Differences in floral resource community composition are likely contributing factors in the differences observed in butterfly communities in the sheep and cattle-grazed pastures, as the sheep-grazed sites may not have had the specific resources some butterfly species require (Poyry et al 2004, Smith & Chery 2014, Cutter et al 2021, Cutter et al 2022). These results mirror previous work conducted at these sites in the past (Cutter et al 2021, Cutter et al 2022), further emphasizing that high priority should be put on grazer species selection by landowners and conservationists alike in the future.

It is important to note that this study had limitations. We were limited by the influences of the extreme weather events that took place during the course of this study. Extreme droughts, particularly in 2017, 2020, and 2021 took place across the state of North Dakota, with it striking particularly hard in Adams county (Average Temperature (1981-2010) 2021, Drought Conditions for Adams County 2021). It is well documented that drought deters both forb and grass growth in grasslands (Tilman & El Haddi 1992). As these were the initial years this management framework was being implemented at these sites, this likely had a large influence on our results, as the expected decreased floral resource availability possibly decreased butterfly abundance and potentially diversity (Fuhlendorf & Engle 2001, Fuhlendorf & Engle 2004, Ricketts & Sandercock 2016). As the use of PBG continues and more data is collected at these sites with the dynamic climate associated with the Northern Great Plains, we will likely better understand how effective PBG is at maintaining floristic resources and butterfly communities on post-CRP landscapes. Additionally, we did not have a control site for comparison purposes which is why we focused on making comparisons within the post-CRP patch-burn grazed framework (Claassen 2011, Cutter et al 2021, Cutter et al 2022). Further insight may be gained from more replication and additional treatments involving more traditional grazing methods (season-long grazing) to determine the true effectiveness of PBG relative to other management practices in the Northern Great Plains region.

Through the course of this study, we were able to demonstrate how managing post-CRP landscapes with patch-burn grazing can create a mosaic landscape in terms of both grassland structure and composition. Furthermore, fire and grazing created patches with distinct floral resource and butterfly communities within post-CRP pastures. This study further showed that butterflies exhibit site selection, implying further research on insect (particularly pollinator) site selection is warranted. Increased knowledge of this will help land managers and conservationists make more informed decisions regarding grassland management in the future (McNew et al 2015, Skagen et al 2018, Duquette et al 2020, Kraft et al 2021). The future effects of reduced yellow sweet clover cover are also warranted, as well as monitoring the spread of invasives across the pastures, as these will potentially drastically impact the overall forb community. Grazer species had a distinct impact on the effectiveness of PBG as a management framework in these post-CRP lands on butterfly and floral resource communities, further reinforcing what has been observed previously (Cutter et al 2021, Cutter et al 2022). Overall, this study shows that PBG can potentially serve as an effective grassland management framework not only in the Northern Great Plains, but also in post-CRP landscapes. PBG should be promoted by conservationists to post-CRP landowners as an alternative to row-crop implementation. This will allow landowners to be have more choices that align with different values for managing their land. Further promotion of working landscapes as a post-CRP grassland management alternative across the Great Plains will increase total heterogeneity, promoting not only butterfly and flowering resource communities, but North American grassland biodiversity.

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CHAPTER 2: FACTORS AFFECTING FLORAL ENHANCEMENT THROUGH SEEDING ON POST-CONSERVATION RESERVE PROGRAM (CRP) LANDSCAPES

Introduction

Grasslands are important to biological diversity and the provisioning of ecosystem services that benefit society, but they are also some of the most threatened ecosystems in the world (Ceballos et al 2010, Gurney et al 2015, Davis et al 2016). Grasslands provide habitat to many endemic species that are adapted to open environments (Stephens et al 2008, Davis et al 2016). For pollinators in particular, such as many butterfly and bee species, grasslands serve as important foraging and nesting grounds (Szigeti et al 2016). Unfortunately, grasslands are continually lost to development for agriculture due to their fertile soils, and only 20% of North America's grasslands remain undeveloped today (Ceballos et al 2010, Gage et al 2016). Furthermore, grassland fragmentation, which is often associated with agricultural development, can increase invasion potential from exotic and invasive species applying additional pressures to proper functioning of the remaining grasslands (Vogel et al 2007, Ceballos 2010, Fuhlendorf et al 2012, DiAllesandro et al 2013). These losses and increased habitat fragmentation have led to reduced biodiversity (Stephens et al 2008, Pillsbury et al 2011). In order to conserve grassland species, particularly pollinators, we need to improve management of grazed, working landscapes and marginal lands.

The United States Department of Agriculture (USDA) developed the Conservation Reserve Program (CRP) in 1985 to protect soil (United States Department of Agriculture Farm Service Agency 2021). This program incentivized the creation of perennial cover on private lands previously used in crop production, retiring the land for a period of 10-15 years (United States Department of Agriculture Farm Service Agency 2021). The main goal of the program was to improve soil quality and prevent erosion, but the program secondarily created many grasslands, particularly in the Great Plains region (United States Department of Agriculture Farm Service Agency 2021). At the peak of the CRP, over 14 million hectares of land were enrolled (Skaggs et al 1994, Cooper & Osborn 1998, Chang & Boisvert 2009, Sullivan et al 2011, United States Department of Agriculture Farm Service Agency 2021). Today, much of the land that was previously enrolled in the CRP is not being re-enrolled, leading to substantial losses of grasslands due to changes in policy and more appealing financial incentives related to crop production (USDA-FSA, 2007, 2020). As CRP contracts have expired, much of the land is converted back to row crops (Wu 2000). However, post-CRP grasslands have the potential to be managed as working landscapes (used for both production and conservation) that can maintain or even improve the habitat quality for wildlife while still supporting landowners' financial livelihoods (Morandin et al 2007).

Previous research demonstrates that many grassland species utilize and benefit from CRP land, especially a variety of bird species (Johnson and Schwartz 1993, Herkert 1998, Herkert 2007, Davis 2016, Ricketts and Sandercock 2016). Additionally, commercial honey bees have benefitted from proximity to CRP land (Otto et al 2018, Ricigliano et al 2019). Limited research has been done investigating the usefulness of CRP for native insect pollinators, but insect pollinators are economically important, contributing approximately $234 billion to the worldwide economy annually (Gallai et al 2009). Over one third of crops and animal products produced in the United States are solely pollinated by insects (Aizen et al 2009). Unfortunately, insect pollinator populations have declined rapidly in recent years, mainly due to habitat fragmentation and loss (Cane and Tepedino 2001, Kluser and Peduzzi 2007, Potts et al 2010). Expiring CRP lands may provide additional habitat for pollinators, but these landscape may not always host the proper floral resources necessary for all species (Bach et al 2012). As the original purpose of the CRP was not to promote grassland diversity, many seed mixes used during plantings contained limited forbs (Bach et al 2012). In order to better conserve these important pollinators, we may need to increase floral abundance to make low-diversity plantings such as CRP lands useful to pollinators.

Structural and compositional grassland diversity are known to drive biodiversity (Rohr et al 2018). For insect pollinators, vegetation structure is important for nesting and protection (Potts et al 2009) and species composition is also important for foraging and reproduction (Potts et al 2009, Bendel et al 2019). Although the highly diverse CP42 pollinator seed mix is currently promoted by the USDA to support pollinator needs (McMinn-Sauder et al 2020, Ashworth et al 2022), early CRP plantings were typically established with low diversity seed mixes composed mainly of grasses and a few non-native forbs (Bach et al 2012). The early focus on limited plant diversity in CRP plantings may result in expiring CRP grasslands that do not currently meet the needs of pollinators requiring diverse floral resources (Bach et al 2012). Furthermore, many older CRP grasslands were left undisturbed (i/e. no fire or grazing) throughout much of the duration of the contract, allowing many former CRP grasslands to become structurally and compositionally homogenous, likely further reducing their usefulness to pollinators. In order to better understand the potential for post-CRP lands to meet the demands of multiple pollinators, further study regarding species composition and structure is needed to allow for better management of post-CRP lands to support biodiversity across the landscape and to enhance or restore CRP lands that are not currently meeting pollinators' needs.

Grassland restoration is important economically as well as ecologically, but it can be a difficult process (Török et al 2011, Palma and Laurance 2015, Swartz et al 2015, Catterall 2018, Pellish et al 2018). In addition to fiscal, labor, and time costs, many natural barriers influence grassland restoration processes (Bricker et al 2010, Rayburn and Laca 2013, Gurney et al 2015, Catterall 2018, Pellish et al 2018, Pearson et al 2019). Temporal phenomena, such as variation in precipitation and temperature can influence seedling growth and establishment (Bakker et al 2003). Drought in particular can greatly reduce seedling establishment and growth (Ooi et al 2012, Seglias et al 2018). Additionally, management practices, such as prescribed fire and grazing, can influence the effectiveness of restoration (Martin and Wilsey 2006, Török et al 2011, Fuhlendorf et al 2012, Rayburn and Laca 2013). If seedlings are able to establish, herbivores can alter community structure through seedling herbivory, sometimes causing young plant mortality (Davidson 1993, Howe and Brown 1999, Howe et al 2006, Fraser and Madson 2008, Orrock and Witter 2010, Catterall 2018). Domestic grazers add another layer of disturbance pressure to the plant community (Davidson 1993, Fraser and Madson 2008). Domestic livestock herbivory is often intentionally left out or entirely overlooked in restoration efforts despite the known community-altering effects it can have (Janzen 1969, Janzen 1971, Davidson 1993, Catterall 2018, Pellish et al 2018). Some landowners remove livestock after seeding in an attempt to increase establishment, but there have been few comparison studies in the past that determine if this is warranted (Davidson 1993, Fraser and Madson 2008). Herbivory of young plants during restoration efforts has not been evaluated in many landscapes and may play an important role when attempting forb enhancement practices.

In our study, we wanted to understand seedling establishment in post-CRP land in order to enhance flowering forb communities for pollinator use while maintaining livestock grazing during restoration efforts. To do this, we utilized patch-burn grazing (PBG) deploying fire to remove litter and expose bare ground prior to seeding, which we expected to facilitate seed germination and expression. Specifically, we examined (1) the effectiveness of seeding native forbs in low diversity, post-CRP grasslands managed with PBG, and (2) the effects of potential environmental factors (precipitation, temperature, & herbivory) on native seedling establishment.

Methods

Study Site

We conducted our study on private lands managed with PBG by the Hettinger Research Extension Center (HREC), located in Adams county in Hettinger, North Dakota (46^{O}0'11.8"N, -102^{O}38'37.3194"W). We used six, 65ha pastures, three of which received season-long grazing by sheep and three by cattle at a stocking rate of 0.5–0.6ha AUM $^{-1}$ (animal unit month). Livestock grazed each pasture from late May to September. We divided each pasture into four equal patches with mineral soil fire breaks. We burned one patch per pasture annually during the dormant season (Vermeire et al 2004, Augustine & Derner 2014). The study sites were in the CRP for approximately 30 years, and the current plant communities were composed mainly of intermediate wheatgrass (*Elymus hispidus* (Opiz) Melderis), alfalfa (*Medicago sativa* L.), crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), and yellow sweet clover (*Melilotus officinalis* L.) (Geaumont et al 2017). Soils in this region were mainly fine, sandy loams at a zero to nine percent slope. Dominant ecological sites at research pastures included Sandy, Loamy, Clayey, and Saline lowland (Web Soil Survey 2022).

This study took place during two periods of drought. According to the National Integrated Drought Information System, the study seasons were characterized by moderate-exceptional drought (Drought Conditions for Adams County 2021). The 30-year temperature average during the field season (May-August) ranged from 12-21^{O}C per month, with the temperature average during the project study period (2020-21) ranging from 11-25^{O}C per month

(Average Temperature (1981-2010) 2021, NDAWN 2021). Average temperature levels were mostly higher than the 30 year average (Fig. 2.1A). The average growing season precipitation fluctuated a bit more, but overall levels were also lower than the 30 year average (Fig. 2.1B). The 30-year precipitation average ranged from 4.45-7.62cm per month, but the average precipitation level during the project study period (2020-21) ranged from 1-11cm per month (NDAWN 2021, Precipitation (1981-2010) 2021).

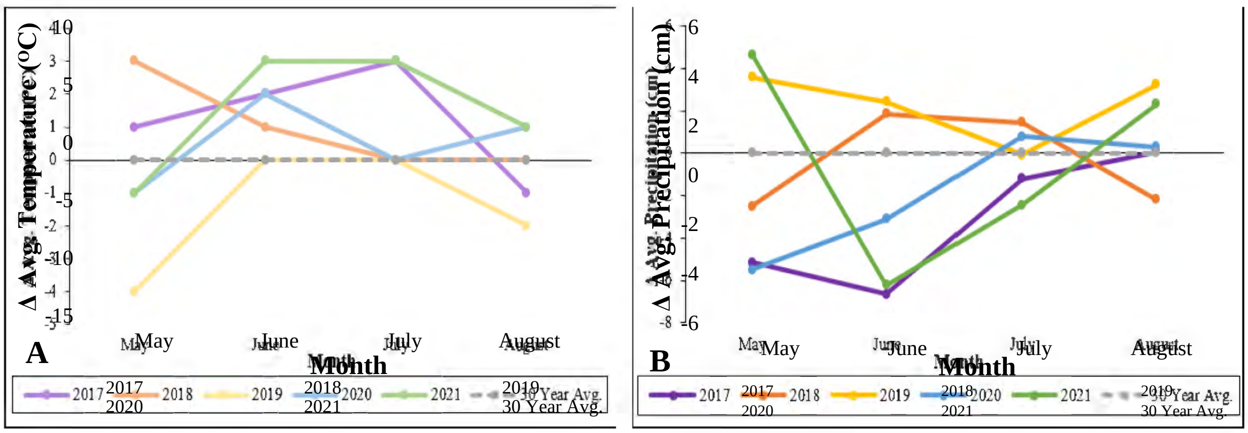

Figure 2.1: The average change in temperature (A) and precipitation (B) per month during the years over-seeding occurred (2017-2021) from the 30 year average (dotted grey lines) (Average Temperature (1981-2010) 2021, NDAWN 2021, Precipitation (1981-2010) 2021) in Hettinger, ND.

We used ArcGIS to establish five, 0.4ha plots positioned diagonally through each patch across all pastures (20 plots per pasture, 120 plots total) that were used for over-seeding (Fig. 2.2). We seeded each plot soon after burning (March-April) with a seed mix that consisted of 20 native flowering forbs known to benefit pollinators and provide floristic resources throughout the growing season (see Fig. B.1 in Appendix B). We selected forbs based on variation in morphological traits and colors. We seeded five plots annually in the most recently burned patch across all six pastures for a total of 30 restoration plots established per year using two different seeding methods. We broadcasted seed using a spreader targeting a rate of 592-pure live seeds/m^2 from 2017-2019. In 2020 and 2021, we seeded plots with a 2.5m Truex no-till drill. We targeted a similar seeding rate as used during the broadcasting at a seeding depth of 0.6-1.2cm.

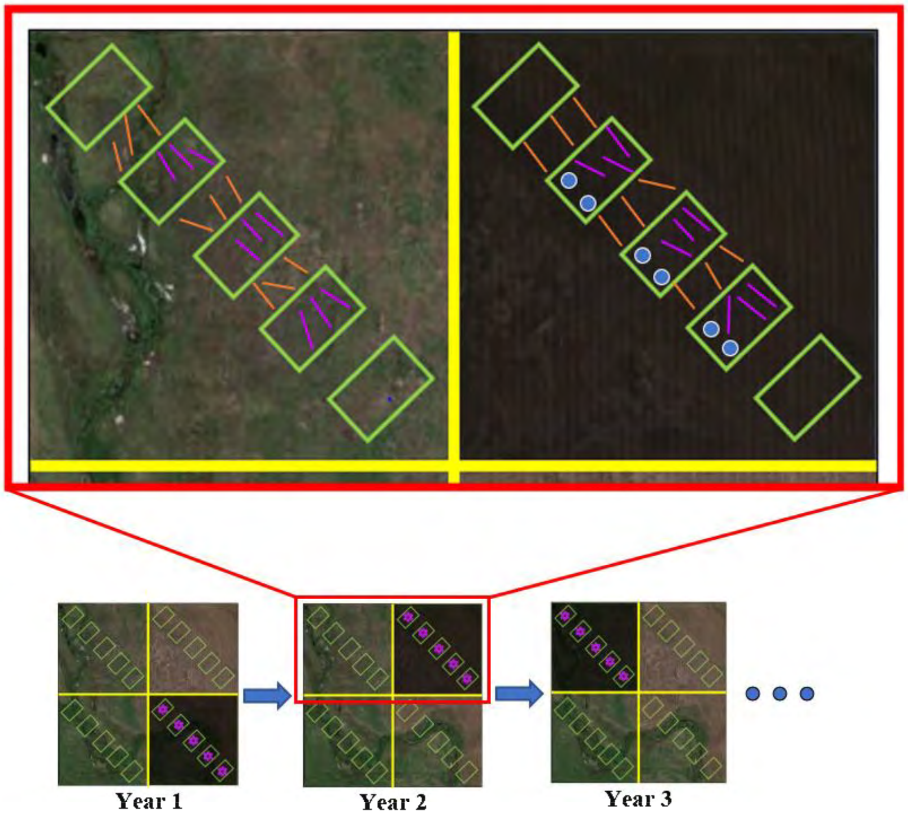

Figure 2.2: A map of a pasture prepared for seeding, and the transects laid out for surveying across all sites during the course of this study (2020-21). *The green rectangles represent the areas that will be seeded. The areas in the patch burned that year (blackened square) are seeded (indicated by the purple flower) that season. As the patch burned rotates from year to year, the areas seeded follow the burned areas. Within the center three seeded areas (green rectangles), large mammal exclosures (blue circles) were set up. Additionally, 25m transects (purple lines) were randomly laid out in the center three seeded areas to assess seedling establishment. Cages were only set up in the currently burned patch, however transects were arranged similarly in every patch. Lastly, 25m transects were randomly laid out in the unseeded areas between the seeded areas (orange lines) for comparison.*

Seedling Establishment Surveys

Large Mammal Exclosures

To allow us to evaluate the impact of domestic and native herbivores on restoration activities, we placed cage exclosures in the three center plots of the newly seeded patches to exclude seed and seedling herbivory during the 2020 and 2021 field seasons. We deployed two cages in each of the center three seeded plots that excluded large mammals in each burned patch, yielding a total of 36 exclosures per year (Fig. 2.2). We used standard hog panel fencing (127 x 488cm) wrapped around t-posts as exclosures (Borchert et al 1989, Kramp et al 1998).

Transect Surveys

We established a single, random, 25m transect in the each of the center three seeded plots in each patch within a pasture to monitor seedling establishment (Fig. 2.2). This resulted in 72 total transects, 36 of which were in the sheep-grazed pastures and 36 were in the cattle-grazed pastures. Each transect was composed of six points spread 5m apart. We surveyed vegetation along each transect once per month from June-August with a $0.25m^2$ quadrat (432 surveyed quadrats each month). Within each quadrat, we recorded the presence or absence of established seedlings, identified them to species, counted the total number per species, and recorded whether or not they were flowering. Additionally, we surveyed for seedlings once per month in each exclosure using the $0.25m^2$ quadrat.

Vegetation Community Surveys

We took a more in-depth look at the plant community once per year during peak growth (end of June to July). We randomly placed 72, 25m transects per pasture, half in seeded areas and half in unseeded areas, for a total of 432 transects. Each transect was composed of six points separated by 5m, resulting in 2,592 survey points overall (1,296 in seeded areas and 1,296 in unseeded areas) (Fig. 2.2).

At each survey point, we used a $0.25m^2$ quadrat to assess vegetation. After identifying and recording each species present within the quadrat, we recorded the Daubenmire cover class (0–5%, 5–25%, 25–50%, 50–75%, 75–95%, 95–100%) of each species (Daubenmire 1959), along with the average litter depth (mm). To further assess the effect of herbivory on plant community composition, we quantified community composition and litter depth in each of the large mammal exclosures following the same methodology.

Data Analysis

We organized the data by grazer type, climactic influences, and exclosure presence on both planted seedling establishment as well as the overall plant community. We averaged data across each classification to determine the effects of each. We plotted the average number of each seedling species detected per year, the difference in seedling presence between seeded versus non-seeded areas, and the overall proportion of the forb community that our target seedling species made up in order to determine the effectiveness of the seeding overall. We used ANOVA (function *aov*) to determine significant differences between each vegetative cover class category between sites grazed by sheep and cattle. We also used ANOVA's to compare the seedling abundance in areas intentionally seeded versus not. We determined factors with p-values < 0.05 to be significant. Within these models, we also ran tukey post hoc tests (function *TukeyHSD*) to compare significant differences among individual factors within the TSF patches. Factors with a $p<0.05$ were determined to be significant.

Since multiple variables could affect seedling abundance, we created an a priori candidate model set to compare models of best fit using an Akaike Information Criterion (AIC) approach (Burnham et al 2011). We created various models with singular and additive combinations of variables of interest and 2 interactions (see Table B.2 in Appendix B). We used site characteristics (i.e., grazer species (sheep or cattle) and exclosure presence) and climate variables (i.e. temperature and precipitation) to model the abundance of planted seedlings to test our hypothesis that climactic and environmental characteristics affect seedling establishment. We included both year and site as random effects to allow to account for temporal and locational variability, as characteristics within these variables can change over time. We tested for an interaction between temperature as well as precipitation and seedling abundance because drought conditions (i.e. high temperatures and low precipitation) typically lead to reductions in seedling establishment (Carter & Blair 2012, Ooi et al 2012, Seglias et al 2018, Yi et al 2019). We tested for an interaction between grazer species and seedling abundance because sheep and cattle have different grazing mechanisms, and this could potentially affect seedling establishment (Fuhlendorf & Engle 2004, Helzer 2011, Ricketts & Sandercock 2016, Cutter et al 2021). We tested for an interaction between exclosure presence and seedling abundance because reduced herbivory pressures could potentially lead to greater seedling establishment (Davidson 1993, Howe and Brown 1999, Howe et al 2006, Fraser and Madson 2008, Orrock and Witter 2010, Catterall 2018). We determined that models with a ΔAIC < 2 potentially contained highly influential factors, models with a ΔAIC 2-4 potentially contained medium influential factors, and models with a ΔAIC ≥ 4 likely contained factors with little model influence (Burnham et al 2011). Models with a ΔAIC > 4 were disregarded as uninfluential. All models with a ΔAIC < 4 were plotted using the *plot_model* function in R. Factors with a confidence interval that did not cross zero were considered potentially significant in influencing seedling abundance.

Results

Seedling Establishment

Seedling establishment was low across all sites. The most prominent seeded forb was western yarrow (*Achillea milletolium occidentalis* (L.) DC), making up 65% of the total seedlings observed (Fig. 2.3). All seeded species, excluding false sunflower (*Heliopsis helianthoides* L.) and golden alexander (*Zizia aurea* L.), were observed at least once during the course of this study. Average western yarrow abundance was approximately 722.5±210.5

flowering stems per year. For the remaining 19 seeded species, the average abundance was only 20±4.50 flowering stems per year across all transects.

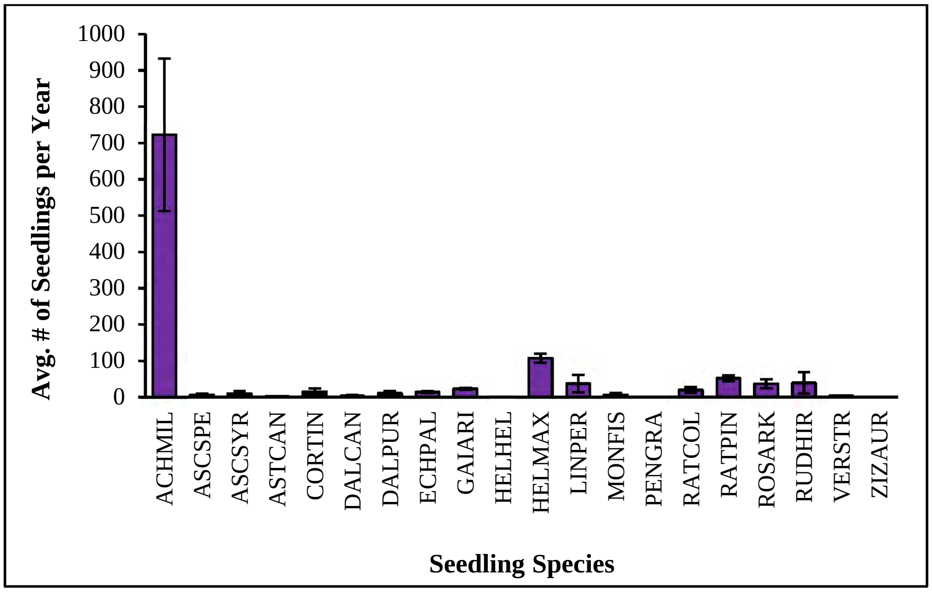

Figure 2.3: The average number of each seedling species observed per year across all sites over the 2020-2021 field seasons. *Error bars represent standard errors. Key to forb name codes can be found in Appendix B in Table B.1.*

There was a significant difference in seeded forb cover in plots that were intentionally seeded compared to those that were not (df=5830, f=3813, p=<0.000) (Fig. 2.4). Seeded plots were covered more by seeded forbs than non-seeded plots but both areas had low seedling cover overall, making up < 5% of site canopy cover.

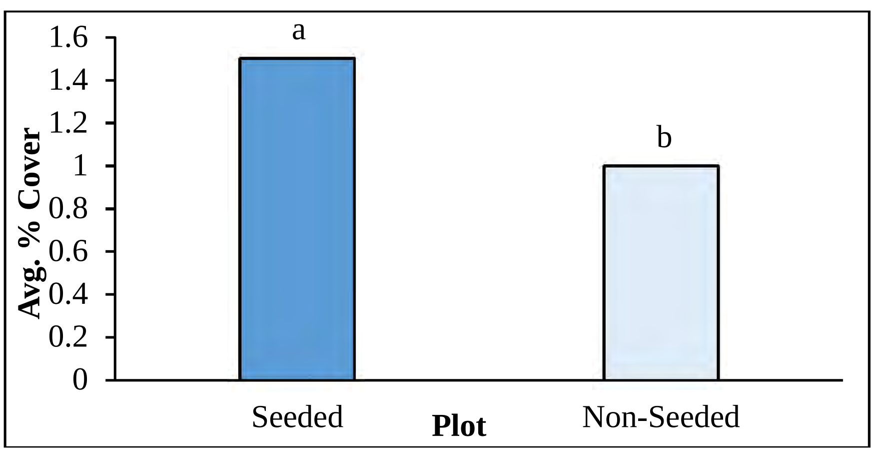

Figure 2.4: The average percent cover of all seeded species in the seeded versus non-seeded plots across all study sites during the 2020-21 field seasons. *Error bars represent standard errors. "a" and "b" represent significantly different values (p<0.05).*

Seedling Abundance

We generated 15 models predicting the influence of each environmental factor (Temperature (^{O}C), Precipitation (Precip.), Grazer Species (Sheep or Cattle), and Large Mammal Exclosure Presence (see Table B.2 in Appendix B). Year and Site were included in each model as random effects. Out of all models, three had a ΔAIC between 0-4, indicating that they were the most informative models, and the factors they contained potentially influenced seedling abundance. The best model predicting seedling abundance included precipitation as the only factor (Fig. 2.5). The next two models (Precip + Grazer and Precip + Exclosure) had ΔAIC between 2-4, which we considered moderately important in our criteria. All other models were less important for seedling abundance ΔAIC > 4. However, all model parameters except exclosure had confidence intervals that overlapped with zero, indicating they were not significant predictors of seedling establishment.

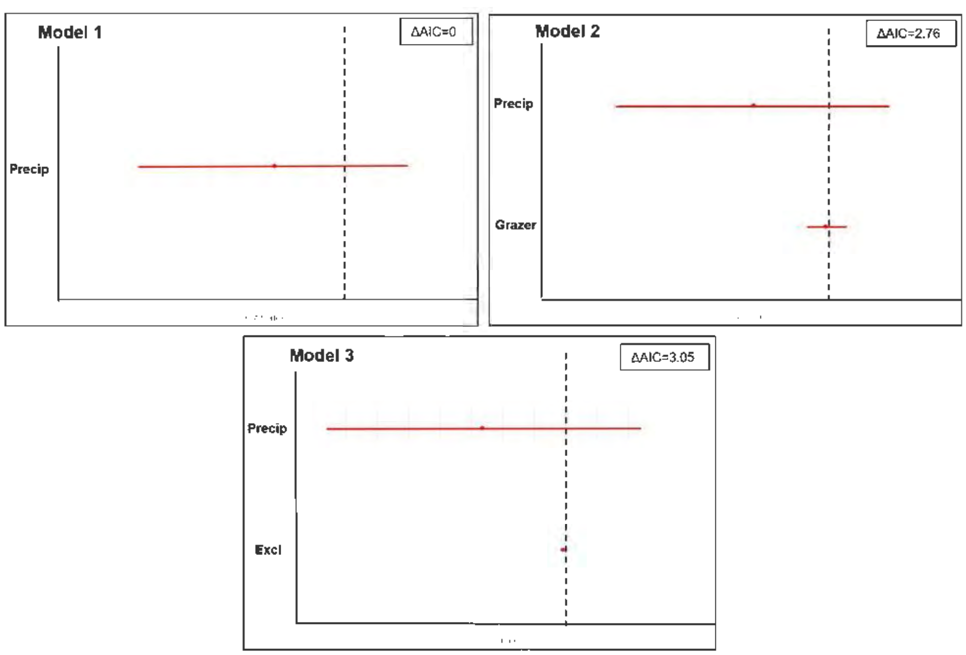

Figure 2.5: The models to determine the most significant factors predicting planted seedling abundance in the seeded plots of all pastures during the course of this study (2020-21). *Factors included in analysis included: Temperature (^{O}C) (Temp.), Precipitation (cm) (Precip.), Grazer Species (Sheep or Cattle) (Grazer), and Large Mammal Exclosure Presence (Excl.). Year and Site were included in each model as random effects.*

Overall Vegetative Community

We were able to identify 106 total plant species (16 grasses, 87 forbs, and 3 others) across all sites. Cattle-grazed pastures were composed of 101 plant species (15 grasses, 83 forbs, and 3 other), and sheep pastures were composed of 72 plant species (10 grasses, 61 forbs, and 1 other). All vegetative cover classes of cattle versus sheep-grazed pastures were significantly different (Fig. 2.6). In both pasture types, land cover consisted of mainly grasses (approximately 50% in cattle, 60% in sheep (df=5830, f=304.7, p<0.000)), followed by ground litter (approximately 30% in cattle, 40% in sheep (df=5830, f=80.6, p=<0.000)). At cattle-grazed sites however, forbs made up a large proportion of land cover (approximately 25-50%), whereas forbs only occupied approximately 5% of sheep-grazed sites (df=5830, f=2034, p=<0.000). Cattle-grazed pastures also had a greater proportion of bare ground compared to sheep-grazed sites (df=5830, f=97.85, p=<0.000). Other plant species and standing litter were also significantly different in cattle versus sheep-grazed sites, although to a lesser degree (Other: df=5830, f=10.74, p=0.001, Standing Litter: df=5830, f=8.88, p=0.003).

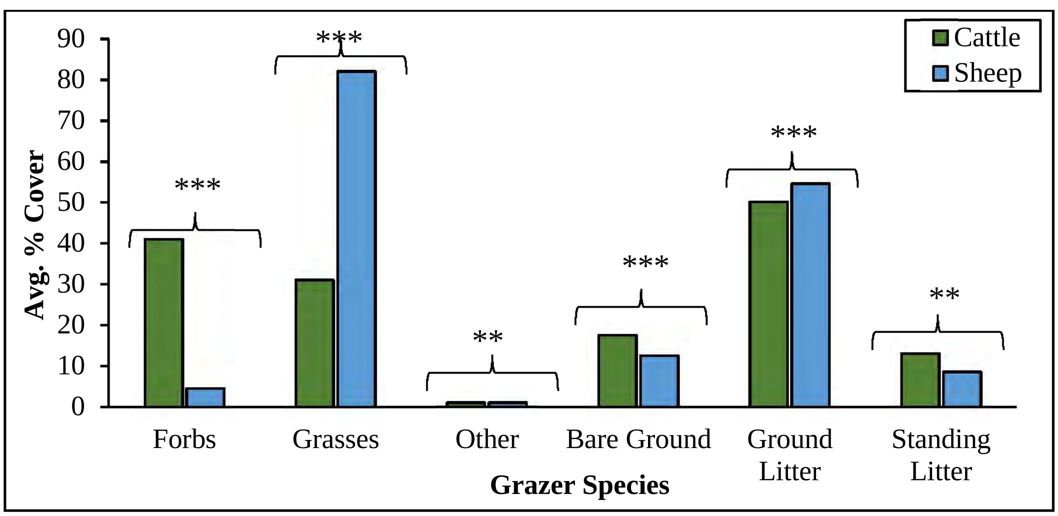

Figure 2.6: The average percent cover of each vegetative community category at sites grazed by cattle versus sheep throughout the study (2020-21). *Error bars represent standard errors. "Other" indicates species that do not fall into the "Forbs" or "Grasses" categories. The following symbols represent the associated levels of significant differences between Vegetative Cover pairs: < 0.000 '***', 0.001 '**', 0.01 '*', 0.05 '+'.*

The forb community differed in cattle versus sheep-grazed pastures (df=5830, f=2034, p=<0.000) (Fig. 2.7). The forbs seeded during the course of this study made up a low proportion of the overall forb community. With both grazer species, a small proportion of the overall forb community was composed of species that are considered non-native and/or invasive ("Noxious"), such as field bindweed (*Convolvulus arvensis* L.), leafy spurge (*Euphorbia esula* L.), and field pennycress (*Thlaspi arvense* L.). For cattle-grazed sites, the overall forb community was dominated "Other" forb species (i.e. species not seeded but not considered non-native and/or invasive) (78%), followed by the "Noxious" species (15%), and finally the seeded forbs (7%). The overall forb community of sheep-grazed sites was a bit more evenly distributed, with "Other" species dominating the community (37%). Seeded forbs made up a greater proportion of the sheep-grazed forb community than cattle-grazed sites (16%), followed by "Noxious" species (6%).

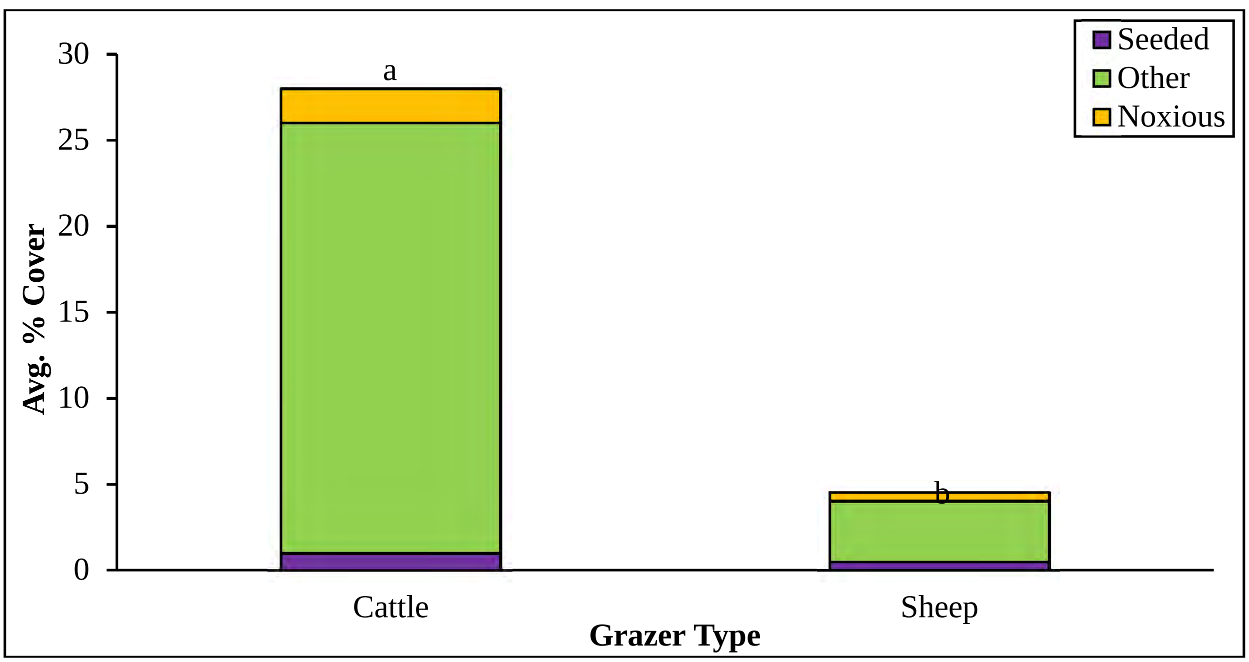

Figure 2.7: The average percent cover for each classification of forb in sites grazed by cattle versus sheep throughout the study (2020-21). *Error bars represent standard errors. "Seeded" indicates forbs seeded during the course of this study, "Other" indicates another native flowering forb, and "Noxious" indicates a non-native and/or invasive species. "a" and "b" represent significantly different values.*

Discussion

Seedling establishment was low overall, but we did see a significantly greater number of seedlings in plots that were intentionally seeded compared to those that were not. Also, all except two of the species planted during this study were observed. Precipitation was likely an influential factor in determining seedling abundance, indicating that the drought likely played a large role in low establishment. Large mammal exclosure presence and possibly grazer species were also influential factors in determining seedling abundance. This indicates that herbivory also likely played a role in seedling establishment, which is often overlooked during restoration efforts. The overall vegetative community differed in sites grazed by sheep versus those grazed by cattle, with cattle pastures hosting a greater percent cover of forbs, but the target seeded forbs made up a low proportion of the forb community as a whole.

Large mammal exclosure presence was a potentially influential factor in model creation, indicating that herbivory likely also played a role in seedling establishment. Herbivores, particularly domestic grazers, are known to have strong effects on vegetative community composition and structure, sometimes even causing young plant mortality (Davidson 1993, Howe and Brown 1999, Howe et al 2006, Fraser and Madson 2008, Orrock and Witter 2010, Catterall 2018). This is often overlooked during restoration efforts, so our study shows that this is something that may need to be further addressed in the future (Janzen 1969, Janzen 1971, Davidson 1993, Catterall 2018, Pellish et al 2018). Large mammal deterrence or complete removal from areas that are being restored may be warranted if seedlings are to properly establish. Small mammal herbivory and granivory are also known to have community-altering effects (Janzen 1971, Bricker et al 2010, Gurney et al 2015, Pellish et al 2018, Pearson et al 2019). This is another avenue of research that warrants further investigation.

Grazer species was a potentially influential factor in best model creation. We also observed different plant communities in sheep versus cattle-grazed areas. Sites grazed by sheep reduced both floral abundance and richness as compared to cattle-grazed sites, likely due to the differing feeding mechanisms. Sheep are more selective grazers, often selecting for forbs due to the increased energy burned during feeding due to their overall smaller size (Fuhlendorf & Engle 2004, Helzer 2011, Ricketts & Sandercock 2016, Cutter et al 2021, Cutter et al 2022). Cattle are more often observed feeding on grasses rather than seeking out flowering forbs (Helzer 2011, Cutter et al 2021, Cutter et al 2022). These differing feeding mechanisms are likely the reason the sites grazed by sheep had lower forb cover than cattle-grazed pastures. The impacts grazer species had on seeded forb establishment were not directly studied during this research, but warrant further investigation.

Drought conditions, particularly the low levels of precipitation that occurred during this study, were likely influential on seedling establishment. The research sites experienced what the National Integrated Drought Information System classifies as “moderate” to “exceptional” drought during this study (Drought Conditions for Adams County 2021). It is known that water availability is important for seedling growth and expression to take place (Carter & Blair 2012, Yi et al 2019). In the grasslands of the Northern Great Plains in particular, many native grassland species are adapted to stay dormant during years of drought until better conditions are achieved (Ooi et al 2012, Seglias et al 2018). As these were the initial years that no-till drill seeding took place, this likely had a large influence on our results (Fuhlendorf & Engle 2001, Fuhlendorf & Engle 2004, Ricketts & Sandercock 2016). If better climactic conditions occur in the future, some of these previously seeded areas may see more expression (Ooi et al 2012, Seglias et al 2018, Yi et al 2019).

Another potential influence on seedling establishment was the vegetative community already established in these areas. In particular, it is important to note some non-native and/or invasive species were present at sites. Although some forbs, such as yellow sweet clover, were originally intentionally seeded due to their ability to establish cover quickly, these forbs can be highly competitive and make establishment of seedlings difficult (Wolf et al 2003, Dickson et al 2010). This is another factor that may need to be addressed in the future if forb enhancement of the overall vegetative community is to be effective in better serving the pollinator community. Also, invasive grasses (such as Kentucky bluegrass (*Poa pratensis* L.) and smooth brome (*Bromus inermis* Leyss)) dominated most sites. Although their effects on forb seedling recruitment has not been observed in the literature, these grasses have been shown to deter native grass growth, implying native forb growth may be affected as well (Dillemuth et al 2009, Palit et al 2021). However, late spring burns (like those conducted during this study) have been shown as a promising control strategy, as these are when grass root reserves are at their lowest (Salesman & Thomsen 2011). This likely mitigated these effects on forb seedling establishment to some degree. Herbicides (particularly imazapic) have also shown promise in controlling invasive grasses for seeding efforts (Hendrickson & Lund 2010, Salesman & Thomsen 2011). This is another potential direction for post-CRP management to take to further improve floral resource establishment.

Although not often, it is also important to note that large mammal exclosures were sometimes damaged, which could have influenced our results. Particularly in the cattle-grazed pastures, large mammal exclosures would be moved or even knocked over from cattle rubbing on the t-posts and hog paneling, due to a lack of other areas in some of the pastures for cattle to scratch. If exclosure design was improved in the future to potentially deter a greater number of mammals, seedling abundance may be improved in the future (Davidson 1993, Howe and Brown 1999, Howe et al 2006, Fraser and Madson 2008, Orrock and Witter 2010, Catterall 2018).

The results of our study show that many factors influence post-CRP forb community enhancement. In particular, herbivory warrants further investigation in the future, as its associated factors were significant in model creation. Our study showed that many factors, herbivory included, need to be considered when conservationists and land managers plan restoration efforts, particularly for conserving pollinator communities (McNew et al 2015, Skagen et al 2018, Duquette et al 2020, Kraft et al 2021). Further research, such as the potential effects improved weather conditions as well as small mammal herbivory and granivory have on seedling establishment, are still necessary to make post-CRP restoration and enhancement even more successful. This will be valuable information for landowners and conservationists to improve grassland connectivity and biodiversity across the Northern Great Plains. It is important that studies like this continue so that we can learn more about improving pollinator resources worldwide.

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APPENDIX A. SUPPLEMENTARY MATERIALS FOR CHAPTER 1

Table A.1: Floral resource abundances over time. *Total # of flowering stems observed across all sites over the course of the study. Species name abbreviations correspond with the first three letters of the species' genus followed by the first three letters of the specific epithet.*

Species	2017	2018	2019	2020	2021	total/sp	% of total
MEDSAT	32582	44727	61201	68370	9041	215921	69.14%
MELOFF	71	494	17219	25596	7	43387	13.89%
ACHMIL	1241	3570	5097	3282	857	14047	4.50%
CONARV	724	2828	3387	3629	551	11119	3.56%
THLARV	151	1080	4171	398	25	5825	1.87%
DESSOP	216	475	4913	69	0	5673	1.82%
CAMMIC	256	394	1892	0	0	2542	0.81%
TAROFF	14	635	796	101	89	1635	0.52%
EUPESU	282	273	593	306	120	1574	0.50%
CIRARV	125	865	194	207	101	1492	0.48%
ERIMOD	0	0	0	958	14	972	0.31%
CORTIN	33	46	60	587	218	944	0.30%
SALSPP	0	881	0	0	0	881	0.28%
DRANEM	0	22	572	0	0	594	0.19%
ANTPAR	9	41	78	243	111	482	0.15%
GRISQU	15	261	12	87	89	464	0.15%
DESPIN	0	0	416	0	0	416	0.13%
POTARG	0	8	239	67	18	332	0.11%
VICAME	29	40	203	35	3	310	0.10%
ALLTEX	1	7	257	0	0	265	0.08%
CHEALB	0	8	221	0	0	229	0.07%
POTNOR	24	131	0	19	7	181	0.06%
ERYCHE	0	0	179	0	0	179	0.06%
HELMAX	0	70	1	102	6	179	0.06%
VERSTR	0	0	0	146	33	179	0.06%
PEDARG	12	6	84	25	24	151	0.05%
RUDHIR	0	0	0	120	29	149	0.05%
RUMCRI	0	0	147	0	0	147	0.05%
SYMERI	4	44	86	7	0	141	0.05%
CERARV	0	0	131	0	0	131	0.04%
LOTUNI	0	0	119	0	0	119	0.04%
CIRUND	93	7	7	2	9	118	0.04%
RATPIN	0	0	0	43	58	101	0.03%
ASTLAX	0	3	92	0	0	95	0.03%
SOLMIS	0	39	55	0	0	94	0.03%
THERHO	0	0	82	0	0	82	0.03%
TRIMAR	0	66	0	0	0	66	0.02%

Table A.1: Floral resource abundances over time (continued). *Total # of flowering stems observed across all sites over the course of the study. Species name abbreviations correspond with the first three letters of the species' genus followed by the first three letters of the specific epithet.*

Species	2017	2018	2019	2020	2021	total/sp	% of total
ERYCAP	2	2	0	58	0	62	0.02%
PHLHOO	0	54	0	0	5	59	0.02%
GLYLEP	1	47	10	0	0	58	0.02%
DALPUR	1	0	11	42	1	55	0.02%
STEGRA	0	0	0	53	0	53	0.02%
ARACOL	0	0	51	0	0	51	0.02%
SISALT	5	39	7	0	0	51	0.02%
RANLON	0	0	0	44	0	44	0.01%
ERISTR	2	2	32	0	5	41	0.01%
HETVIL	0	4	16	20	0	40	0.01%
LACTAT	2	8	18	6	2	36	0.01%
LIAPUN	0	0	0	2	32	34	0.01%
NEPCAT	31	0	0	0	0	31	0.01%
ERIGLA	0	0	29	0	0	29	0.01%
OENSUF	0	22	2	3	0	27	0.01%
TURGLA	0	0	0	25	0	25	0.01%
LYCASP	0	23	0	0	0	23	0.01%
LEPDEN	0	0	22	0	0	22	0.01%
PENGRAC	0	0	20	0	2	22	0.01%
SOLRIG	0	22	0	0	0	22	0.01%
SOLCAN	0	3	0	16	0	19	0.01%
ALOPRA	0	0	0	17	0	17	0.01%
SPHCOC	5	0	0	6	3	14	0.00%
SONOLE	1	12	0	0	0	13	0.00%
TEUCAN	0	0	13	0	0	13	0.00%
ASTAGR	0	1	9	0	2	12	0.00%
ERYASP	0	0	11	0	1	12	0.00%
HELPAU	5	7	0	0	0	12	0.00%
LINPER	0	0	0	2	10	12	0.00%
RATCOL	2	6	1	0	3	12	0.00%
LYGJUN	6	0	1	1	3	11	0.00%
MENARV	0	0	11	0	0	11	0.00%
HELANN	0	10	0	0	0	10	0.00%
SONASP	0	0	10	0	0	10	0.00%
ECHANG	0	2	6	0	0	8	0.00%
SOLMOL	0	0	0	5	3	8	0.00%
TRADUB	0	1	2	1	4	8	0.00%

Table A.1: Floral resource abundances over time (continued). *Total # of flowering stems observed across all sites over the course of the study. Species name abbreviations correspond with the first three letters of the species' genus followed by the first three letters of the specific epithet.*

Species	**2017**	**2018**	**2019**	**2020**	**2021**	**total/sp**	**% of total**
MEDLUP	0	0	0	7	0	7	0.00%
OXYLAM	2	2	1	0	2	7	0.00%
PENALB	0	0	0	1	6	7	0.00%
CYNOFF	6	0	0	0	0	6	0.00%
ECHPAL	0	0	0	0	6	6	0.00%
ERYINC	0	0	6	0	0	6	0.00%
LAPOCC	0	0	6	0	0	6	0.00%
LITINC	0	0	5	0	0	5	0.00%
FALCON	0	0	4	0	0	4	0.00%
ALOAEQ	0	0	0	3	0	3	0.00%
CIRFLO	0	0	2	0	1	3	0.00%
GAIARI	0	1	1	0	1	3	0.00%
OENLAC	0	0	0	3	0	3	0.00%
ARAPYC	1	1	0	0	0	2	0.00%
ASCSPE	0	0	2	0	0	2	0.00%
ASTCAN	0	0	0	0	2	2	0.00%
BASSCO	0	2	0	0	0	2	0.00%
BOESTR	0	0	2	0	0	2	0.00%
OXADIL	0	0	2	0	0	2	0.00%
SAGSAG	0	0	0	2	0	2	0.00%
ANTNEG	1	0	0	0	0	1	0.00%
ASTMIS	0	1	0	0	0	1	0.00%
BACROT	1	0	0	0	0	1	0.00%
CALARV	0	0	0	1	0	1	0.00%
COLLIN	0	1	0	0	0	1	0.00%
ERIPHI	0	0	0	0	1	1	0.00%
LACSER	0	0	1	0	0	1	0.00%
LOMFOE	0	0	1	0	0	1	0.00%
OENBIE	0	0	0	0	1	1	0.00%
ORTLUT	0	0	1	0	0	1	0.00%
PENGRA	0	1	0	0	0	1	0.00%
POTPEN	0	0	1	0	0	1	0.00%
ROSARK	0	1	0	0	0	1	0.00%
SENINT	0	0	1	0	0	1	0.00%
Totals:	**35956**	**57296**	**102822**	**104717**	**11506**	**312297**	

Table A.2: Butterfly abundances over time. *Total # of butterflies observed across all sites over the course of the study. Species name abbreviations correspond with the first three letters of the species' genus followed by the first three letters of the specific epithet.*

Species	**2017**	**2018**	**2019**	**2020**	**2021**	**total/sp**	**% of total**
COLPHI	1406	2429	4599	976	786	10196	57.53%
LYCMEL	894	1759	286	180	169	3288	18.55%
PONPRO	51	108	348	236	32	775	4.37%
VANCAR	104	1	496	27	3	631	3.56%
CERPEG	21	22	151	171	217	582	3.28%
COLEUR	53	114	71	129	96	463	2.61%
GLALYG	13	21	38	108	250	430	2.43%
COETUL	37	14	62	157	121	391	2.21%
PHYCOC	2	44	125	57	1	229	1.29%
PHYTHA	0	99	44	15	0	158	0.89%
PIERAP	15	25	7	66	40	153	0.86%
PYRCOM	24	49	35	3	8	119	0.67%
SPEAPH or SPECYB	4	2	20	18	17	61	0.34%
DANPLE	0	9	20	15	13	57	0.32%
VANATA	4	0	34	3	2	43	0.24%
SPEIDA	7	5	9	12	7	40	0.23%
PHYBAT	4	1	17	3	2	27	0.15%
EUPCLA	0	15	6	4	0	25	0.14%
POLTHE	5	0	4	0	4	13	0.07%
VANVIR	2	2	6	2	0	12	0.07%
POLMYS	0	0	4	4	1	9	0.05%
LYCHEL	0	3	0	0	4	7	0.04%
ERYPER	0	0	5	1	0	6	0.03%
PHOCAT	0	0	1	4	1	6	0.03%
BOLSEL	0	0	1	0	0	1	0.01%
CHLGOR	0	0	1	0	0	1	0.01%
ANALOG	0	0	0	0	1	1	0.01%
Totals:	**2646**	**4722**	**6390**	**2191**	**1775**	**17724**	

Table A.3: List of all flowering forb species observed throughout the study and the corresponding species codes.

Species Code	Species Scientific Name	Common Name
ACHMIL	*Achillea milletolium occidentalis*	Common Yarrow
ALLTEX	*Allium textile*	Textile Onion
ALOAEQ	*Alopecurus aequalis*	Short-awn Foxtail
ALOPRA	*Alopecurus pratensis*	Meadow Foxtail
ANTNEG	*Antennaria neglecta*	Field Pussytoes
ANTPAR	*Antennaria parvifolia*	Small-leaf Pussytoes
ARAPYC	*Arabis pycnocarpa*	Hairy Rockcress
ASCSPE	*Asclepias speciosa*	Showy Milkweed
ASTAGR	*Astragalus agrestis*	Field Milkvetch
ASTCAN	*Astragalus canadensis*	Canadian Milkvetch
ASTLAX	*Astragalus laxmannii*	Prairie Milkvetch
ASTMIS	*Astragalus missouriensis*	Missouri Milkvetch
BACROT	*Bacopa rotundifolia*	Roundleaf Water-Hyssop
BASSCO	*Bassia scoparia*	Summer-Cypress
BOESTR	*Boechera stricta*	Drummond's Rockcress
CALARV	*Calendula arvensis*	Field Marigold
CAMMIC	*Camelina microcarpa*	Littlepod False Flax
CERARV	*Cerastium arvense*	Field Chickweed
CHEALB	*Chenopodium album*	Common Lambsquarters
CIRARV	*Cirsium arvense*	Creeping Thistle
CIRFLO	*Cirsium flodmanii*	Flodman's Thistle
CIRUND	*Cirsium undulatum*	Wavyleaf Thistle
COLLIN	*Collomia linearis*	Narrow-leaf Mountain Trumpet
CONARV	*Convolvulus arvensis*	Field Bindweed
CORTIN	*Coreopsis tinctoria*	Plains Coreopsis
CYNOFF	*Cynoglossum officinale*	Hound's-Tongue
DALPUR	*Dalea purpurea*	Purple Prairie Clover
DESPIN	*Descurainia pinnata*	Western Tansymustard
DESSOP	*Descurainia sophia*	Flixweed
DRANEM	*Draba nemorosa*	Wood Whitlow-Grass
ECHANG	*Echinacea angustifolia*	Narrow-leaf Purple Coneflower
ECHPAL	*Echinacea pallida*	Pale Purple Coneflower
ERIGLA	*Erigeron glabellus*	Smooth Fleabane
ERIMOD	*Erigeron modestus*	Plains Fleabane
ERIPHI	*Erigeron philadelphicus*	Philidelphia Fleabane
ERISTR	*Erigeron strigosus*	Daisy Fleabane
ERYASP	*Erigeron strigosus*	Prairie-Rocket Wallflower
ERYCAP	*Erysimum capitatum*	Western Wallflower
ERYCHE	*Erysimum cheiranthoides*	Wormseed Wallflower
ERYINC	*Erysimum inconspicuum*	Small-flower Prairie Wallflower
EUPESU	*Euphorbia esula*	Leafy Spurge

Table A.3: List of all flowering forb species observed throughout the study and the corresponding species codes (continued).

Species Code	Species Scientific Name	Common Name
FALCON	*Fallopia convolvulus*	Black-Bindweed
GAIARI	*Gaillardia aristata*	Great Blanketflower
GLYLEP	*Glycyrrhiza lepidota*	Wild Licorice
GRISQU	*Grindelia squarrosa*	Curlycup Gumweed
HELANN	*Helianthus annuus*	Common Sunflower
HELMAX	*Helianthus maximilani*	Maximillian Sunflower
HELPAU	*Helianthus pauciflorus*	Stiff Sunflower
HETVIL	*Heterotheca villosa*	Hairy Goldenaster
LACSER	*Lactuca serriola*	Prickly Lettuce
LACTAT	*Lactuca tatarica*	Blue Lettuce
LAPOCC	*Lappula occidentalis*	Flatspine Stickseed
LEPDEN	*Lepidium densiflorum*	Common Peppergrass
LIAPUN	*Liatris punctate*	Dotted Gayfeather
LINPER	*Linum perenne*	Blue Flax
LITINC	*Lithospermum incisum*	Narrowleaf Puccoon
LOMFOE	*Lomatium foeniculaceum*	Carrotleaf Desert-Parsley
LOTUNI	*Lotus unifoliatus*	Deer Vetch
LYCASP	*Lycopus asper*	Rough Bugleweed
LYGJUN	*Lygodesmia juncea*	Rush Skeletonplant
MEDLUP	*Medicago lupulina*	Black Medic
MEDSAT	*Medicago sativa*	Alfalfa
MELOFF	*Melilotus officinalis*	Yellow Sweetclover
MENARV	*Mentha arvensis*	Corn Mint
NEPCAT	*Nepeta cataria*	Catnip
OENBIE	*Oenothera biennis*	Common Evening Primrose
OENLAC	*Oenothera laciniata*	Cutleaf Evening Primrose
OENSUF	*Oenothera suffrutescens*	Scarlet Beeblossom
ORTLUT	*Orthocarpus luteus*	Yellow Owl's-Clover
OXADIL	*Oxalis dillenii*	Slender Yellow Woodsorrel
OXYLAM	*Oxytropis lambertii*	Stemless Point-Vetch
PEDARG	*Pediomelum argophyllum*	Silvery Scrufpea
PENALB	*Penstemon albidus*	White-flower Beardtongue
PENGRA	*Penstemon grandiflorus*	Large-flowered Beardtongue
PENGRAC	*Penstemon gracilentus*	Slender Beardtongue
PHLHOO	*Phlox hoodii*	Spiny Phlox
POTARG	*Potentilla argentea*	Silverleaf Cinquefoil
POTNOR	*Potentilla norvegica*	Rough Cinquefoil
POTPEN	*Potentilla pensylvanica*	Prairie Cinquefoil
RANLON	*Ranunculus longirostris*	Longbeak Buttercup
RATCOL	*Ratibida columnifera*	Upright Prairie Coneflower
RATPIN	*Ratibida pinnata*	Grey-headed Coneflower

Table A.3: List of all flowering forb species observed throughout the study and the corresponding species codes (continued).

Species Code	**Species Scientific Name**	**Common Name**
ROSARK	*Rosa arkansana*	Prairie Rose
RUDHIR	*Rudbeckia hirta*	Black-eyed Susan
RUMCRI	*Rumex crispus*	Curled Dock
SAGSAG	*Sagittaria sagittifolia*	Arrowhead
SALSPP	*Salsola kali*	Russian Thistle/Tumbleweed
SENINT	*Senecio integerrimus*	Tall Western Groundsel
SISALT	*Sisymbrium altissimum*	Tall Tumblemustard
SOLCAN	*Solidago canadensis*	Canada Goldenrod
SOLMIS	*Solidago missouriensis*	Missouri Goldenrod
SOLMOL	*Solidago mollis*	Ground Goldenrod
SOLRIG	*Solidago rigida*	Stiff-leaved Goldenrod
SONASP	*Sonchus asper*	Prickly Sowthistle
SONOLE	*Sonchus oleraceus*	Common Sow-Thistle
SPHCOC	*Sphaeralcea coccinea*	Scarlet Globemallow
STEGRA	*Stellaria graminea*	Lesser Stitchwort
SYMERI	*Symphyotrichum ericoides*	White Heath Aster
TAROFF	*Taraxacum officinale*	Common Dandelion
TEUCAN	*Teucrium canadense*	American Germander
THEHRO	*Thermopsis rhombifolia*	Prairie Thermopsis
THLARV	*Thlaspi arvense*	Field Pennycress
TRADUB	*Tragopogon dubius*	Yellow Salsify
TRIMAR	*Triglochin maritima*	Common Arrowgrass
TURGLA	*Turritis glabra*	Tower Mustard
VERSTR	*Verbena stricta*	Hoary Vervain
VICAME	*Vicia americana*	American Vetch

Table A.4: List of all butterfly species observed throughout the study and the corresponding species codes.

Species Code	Species Scientific Name	Common Name
ANALOG	*Anatrytone logan*	Delaware Skipper
BOLSEL	*Boloria selene*	Silver-bordered Fritillary
CERPEG	*Cercyonis pegala*	Common Wood Nymph
CHLGOR	*Chlosyne gorgone*	Gorgone Checkerspot
COETUL	*Coenonympha tullia*	Common Ringlet
COLEUR	*Colias eurytheme*	Orange Sulphur
COLPHI	*Colias philodice*	Clouded Sulphur
DANPLE	*Danaus plexippus*	Monarch
ERYPER	*Erynnis persius*	Persius Duskywing
EUPCLA	*Euptoieta claudia*	Variegated Fritillary
GLALYG	*Glaucopsyche lygdamus*	Silvery Blue
LYCHEL	*Lycaena helloides*	Purplish Copper
LYCMEL	*Lycaeides melissa*	Melissa Blue
PHOCAT	*Pholisora catullus*	Common Sootywing
PHY SP.	*Phyciodes* species	Unknown Crescent Species
PHYBAT	*Phyciodes batesii*	Tawny Crescent
PHYCOC	*Phyciodes cocyta*	Northern Crescent
PHYTHA	*Phyciodes tharos*	Pearl Crescent
PIERAP	*Pieris rapae*	Cabbage White
POL SP.	*Polites* species	Unknown Skipper Species
POLMYS	*Polites mystic*	Long Dash Skipper
POLTHE	*Polites themistocles*	Tawny-edged Skipper
PONPRO	*Pontia protodice*	Checkered White
PYRCOM	*Pyrgus communis*	Common Checkered-Skipper
SPE SP.	*Speyeria* species	Unknown Fritillary Species
SPEAPH or SPECYB	*Speyeria aphrodite* or *Speyeria cybele*	Aphrodite or Great Spangled Fritillary
SPEIDA	*Speyeria idalia*	Regal Fritillary
VANATA	*Vanessa atalanta*	Red Admiral
VANCAR	*Vanessa cardui*	Painted Lady
VANVIR	*Vanessa virginiensis*	American Lady

APPENDIX B. SUPPLEMENTARY MATERIALS FOR CHAPTER 2

MillbornSeeds

Hettinger Pollinator Mix - 1 Acre

Scientific Name	Common Name	PLS LB/Acre	PLS Oz/Acre
Rudbeckia hirta	Black Eyed Susan	0.270	
Gaillardia aristata	Blanketflower	0.500	
Linum perenne	Blue Flax	0.300	
Astragalus canadensis	Canada Milkvetch	0.500	
Asclepias syriaca	Common Milkweed	0.100	
Heliopsis helianthoides	False Sunflower	0.100	
Zizia aurea	Golden Alexanders	0.050	
Ratibida pinnata	Grayhead Coneflower	0.100	
Verbena stricta	Hoary Vervain	0.100	
Helianthus maximiliani	Maximilian Sunflower	0.500	
Echinacea pallida	Pale Purple Coneflower	0.100	
Coreopsis tinctoria	Plains Coreopsis	0.180	
Ratibida columnifera	Prairie Coneflower	0.500	
Rosa arkansana	Prairie Wild Rose	0.100	
Dalea purpurea	Purple Prairie Clover	0.500	
Penstemon grandiflorus	Shell Leaf Penstemon	0.050	
Asclepias speciosa	Showy Milkweed	0.100	
Achillea millefolium var. occidentalis	Western Yarrow	0.070	
Dalea candida	White Prairie Clover	0.100	
Monarda fistulosa	Wild Bergamot	0.100	
	Total	4.320	0.000
	Total Seeding Rate (PLS LB/Acre)	4.320	*Rev Date 02/18/21*

Figure B.1: List of species and their corresponding abundances of the seed mix used across sites. *All 20 species are native grassland forbs used to improve the floral resource community for pollinators.*

Table B.1: List of all seeded forb species in the study and the corresponding species codes. *Species name codes correspond with the first three letters of the species' genus followed by the first three letters of the specific epithet.*

Species Code	Species Scientific Name	Common Name
ACHMIL	*Achillea milletolium occidentalis*	Western Yarrow
ASCSPE	*Asclepias speciosa*	Showy Milkweed
ASCSYR	*Asclepias syriaca*	Common Milkweed
ASTCAN	*Astragalus canadensis*	Canada milkvetch
CORTIN	*Coreopsis tinctoria*	Plains Coreopsis
DALCAN	*Dalea candida*	Antelope White Prairie Clover
DALPUR	*Dalea purpurea*	Purple Prairie Clover
ECHPAL	*Echinacea pallida*	Pale Purple Coneflower
GAIARI	*Gaillardia aristata*	Blanketflower
HELHEL	*Heliopsis helianthoides*	False Sunflower
HELMAX	*Helianthus maximilani*	Medicine Creek Maximilian Sunflower
LINPER	*Linum perenne*	Blue Flax
MONFIS	*Monarda fistulosa*	Wild Bergamont
PENGRA	*Penstemon grapdiflorus*	Shell Leaf Penstemon
RATCOL	*Ratibida columnifera*	(Upright) Prairie Coneflower
RATPIN	*Ratibida pinnata*	Grayhead Coneflower
ROSARK	*Rosa arkansana*	Prairie Wild Rose
RUDHIR	*Rudbeckia hirta*	Black-eyed Susan
VERSTR	*Verbena stricta*	Hoary Vervain
ZIZAUR	*Zizia aurea*	Golden Alexanders

Table B.2: All 15 models produced to determine the most significant factors predicting planted seedling abundance across all seeded plots in all pastures from 2020-21. *Factors included in analysis included: Temperature (^{O}C) (Temp.), Precipitation (cm) (Precip.), Grazer Species (Sheep or Cattle) (Grazer), and Large Mammal Exclosure Presence (Excl.). Year and Site were included in each model as random effects.*

Model	n	K	AIC	ΔAIC	w_i	Correction	AIC_c	ΔAIC_c	AIC_c w_i
Precip	2872	1	6926.257	0	0.596720011	0.001393728	6926.258394	0	0.099992651
Precip+Grazer	2872	2	6929.018	2.761	0.150046915	0.004182642	6929.022183	2.763788914	0.025108395
Precip.+Excl.	2872	2	6929.303	3.046	0.130118817	0.004182642	6929.307183	0.285	0.086712382
Grazer	2872	1	6931.969	5.712	0.034310383	0.001393728	6931.970394	2.663211086	0.026403357
Precip.+Grazer+Excl.	2872	3	6932.067	5.81	0.032669699	0.008368201	6932.075368	0.104974473	0.09487967
Excl.	2872	1	6932.084	5.827	0.032393183	0.001393728	6932.085394	0.010025527	0.099492666
Temp.+Precip.	2872	2	6934.727	8.47	0.008640392	0.004182642	6934.731183	2.645788914	0.026634363
Grazer+Excl.	2872	2	6935.019	8.762	0.007466662	0.004182642	6935.023183	0.292	0.086409419
Temp.+Precip.+Grazer	2872	3	6937.474	11.217	0.002187913	0.008368201	6937.482368	2.459185559	0.029239014
Temperature	2872	1	6937.531	11.274	0.002126437	0.001393728	6937.532394	0.050025527	0.097522579
Temp.+Precip.+Excl.	2872	3	6937.847	11.59	0.001815658	0.008368201	6937.855368	0.322974473	0.085081486
Temp.+Grazer	2872	2	6940.454	14.197	0.000493096	0.004182642	6940.458183	2.602814441	0.027212855
Temp.+Excl.	2872	2	6940.642	14.385	0.000448857	0.004182642	6940.646183	0.188	0.091021586
Temp.+Precip.+Grazer+Excl.	2872	4	6940.601	14.344	0.000458153	0.013951866	6940.614952	-0.031230776	0.10156633
Temp.+Grazer+Excl.	2872	3	6943.57	17.313	0.000103825	0.008368201	6943.578368	2.963416335	0.022723248
Null Model	2872	1	15335.81	8409.553	0	0.001393728	15335.81139	8403.841	0